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AN ELEMENTARY
HANDBOOK OF PHYSICS

AN ELEMENTARY

HANDBOOK OF PHYSICS

WITH 210 DIAGRAMS

BY

WILLIAM ROSSITER

F.R.A.S. F.C.S. F.R.G.S. ETC.

WILLIAM BLACKWOOD AND SONS
EDINBURGH AND LONDON
MDCCCLXXI

I OFFER THIS BOOK TO

JOHN WESTLAKE, ESQUIRE,

OF LINCOLN'S INN, LONDON,

IN ACKNOWLEDGMENT THAT MY EARLIEST LESSONS

IN PHYSICAL SCIENCE

WERE DERIVED FROM HIS TEACHING,

AND

THAT THIS IS THE LEAST OF MY OBLIGATIONS

TO HIM.

WOOTTON BRIDGE, ISLE OF WIGHT,
November 1870.

PREFACE.

I AM often asked to help young men who are preparing for matriculation or scientific degrees at the London University, and to recommend to them books for their further assistance. The fact that I do not know a book at a moderate price that attempts to explain, as well as to describe, the phenomena of Physics, has led to my writing this one. It has occupied the leisure of three years of an exceptionally busy life, and has given to that leisure a purpose and a pleasure that have more than repaid the trouble and expense. If it also helps my pupils and others, I shall have my pleasure increased.

I have to thank many friends for help of various kinds. For the gift and loan of books, I have to thank Professor Tyndall, Professor Balfour Stewart, Professor Grove, W. Spottiswoode, Esq., and W. M. Williams, Esq. Also I am indebted to E. J. Stone, Esq., for permission to visit Greenwich Observatory, and for his guidance over it; to Professor Balfour Stewart for permission to visit Kew Observatory, and for his guidance on two occasions; and to Arthur Hill, Esq. of Bruce Castle, Tottenham, for several valuable suggestions.

In one sense the book is wholly original, being based upon my own experiments and observations. By the light of these

I have read the books mentioned* with more or less care and completeness, and have then made such corrections in the text as seemed desirable. No part of the book is merely a reproduction of part of any other, and there is no quotation in it, excepting a few words from Sir John Herschel; and after this was printed, I found Professor Tyndall has quoted precisely the same passage, but at more length, in his 'Notes on Light,' since published. Excepting figs. 112 and 113 (for which I am indebted to Mr Browning), the drawings are my own, and are all original.

W. R.

WORKING MEN'S COLLEGE,
91 BLACKFRIARS' ROAD, LONDON.

* The Philosophical Transactions of the Royal Society 1660–1869; the Reports of the British Association 1831–1869; 'Heat a Mode of Motion'—Tyndall; Lectures on Sound—Tyndall; Dia-Magnetism, &c.—Tyndall; Notes on Light—Tyndall; Notes on Electricity—Tyndall; Treatise on Heat—Balfour Stewart; Correlation and Continuity—Grove; Die Galvanische Kette—Ohm; La Lumière—Becquerel; The Fuel of the Sun—Williams.

CONTENTS.

CORRIGENDA.

Page 74,	line 45,	*for*	"raise 30°"	*read*	"raise mercury 30°."
" 86,	" 16,	"	"10° C."	"	"– 10° C."
" 89,	" 5,	"	"20° C."	"	"– 20° C."
" 95,	" 12,	"	"light"	"	"lights."
" 103,	" 14,	"	"lights"	"	"light."

" 158, figs. 78, 79, 80, and 81 should be numbered from right to left, instead of from left to right.

AN ELEMENTARY

HANDBOOK OF PHYSICS.

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Thus also, in considering the politics of our own ... , how few realise the truth that the present is only one of a long series of times, and not a platform from which to survey history as a traveller surveys a stormy sea from a safe harbour! If it be difficult to realise the relative value and importance of our own country and the events of our own times, to comprehend their connection with the past and their probable influence on the future, how much more difficult to look at ourselves from outside, to understand our own individual relations to the external world, to realise what seeing, hearing, tasting, feeling, and smell-

AN ELEMENTARY
HANDBOOK OF PHYSICS.

INTRODUCTION.

A MAN lost on an island would compare it with his own country as to its size, climate, vegetation, animal inhabitants, &c., and would find it difficult to consider the two lands as being equally portions of the globe. His own native land would be a fixed unalterable standard in all things. He would not compare the two places each with the other, but would compare the new with the old, the novel with the familiar. Only a specially thoughtful man would take the new as a standard with which to compare the old. So a traveller who passes through many lands at first compares the manners and customs of the people with those of his own nation—only gradually will he compare them amongst themselves, and still more slowly will he review habits of his own countrymen by any standard formed abroad.

Thus also, in considering the politics of our own times, how few realise the truth that the present is only one of a long series of times, and not a platform from which to survey history as a traveller surveys a stormy sea from a safe harbour! If it be difficult to realise the relative value and importance of our own country and the events of our own times, to comprehend their connection with the past and their probable influence on the future, how much more difficult to look at ourselves from outside, to understand our own individual relations to the external world, to realise what seeing, hearing, tasting, feeling, and smell-

ing are! For be it remembered that by these senses, and by these only, are we cognisant of an outer world at all.

Look at a blind man, and consider how different are his impressions of the world to ours. Colour, form, light, and shade—all that make up *beauty*—are to him almost unknown. Think, again, of the deaf man, for whom the music of the human voice never existed, by whom the thunder and the wave-ripple are alike inaudible, and for whom *rhythm* can scarcely exist; and then, again, that by this same man the expression of his feelings by speech is altogether unknown.

Add to the idea of all these deprivations that of the absence of taste, smell, and feeling, and then we may approximately realise the condition to which man would be reduced but for the receptive power of the senses. I say *receptive power*—for it must be borne in mind that seeing, hearing, feeling, smelling, and tasting, are not acts of volition, but of endurance. We cannot see by desiring to see, nor hear by wishing to hear. It is essential that the eye or ear should receive that impulse which we call sight or sound.

It is, then, by our senses of seeing, hearing, feeling, tasting, and smelling, and by these only, that we can become cognisant of what is going on around us. And we have, then, to ask in what manner and by what agency do these senses keep us informed?

The *agency* consists in the organs called the eyes, ears, nose, palate, and a more generally diffused organ, that of feeling, to which no especial name has been assigned. But these organs are no more than the machinery for bringing into contact with external nature the extremities of the various nerves which are really the organs of sense. Two branches of the optic nerve terminate in fine threads within the eyes, and the eyes are but suitable machinery for communicating motion to these nervous extremities, and for protecting them from injury. Two branches of the auricular nerve in the same way terminate within the ears, and these ears are no more or less than suitable machinery for communicating motion to these nerves, and for their protection. Similarly the nose is an arrangement for the protection of the extremities of the nerves of smelling and for communicating motion to them; so of the palate and the nerves of taste. The sense of feeling is more generally diffused, the extremities of these nerves spreading over the whole external and internal surface of the body. But in all cases the nature of the action is the same. Motion or force is communicated to our nerves, and by this action

on these nerves, and by this only, we are enabled to form conceptions of the external world.

But we must remember that the external world is altogether independent of us and our nerves. The world existed, with endless varieties of land and sea, of trees and flowers, with its alternations of day and night, summer and winter, for countless ages before man came on it to see and hear, to work and govern; to wonder, to think, and to discover; to pass through all the gradations of ignorance, presumption, pride, and humility; to learn by long and toilsome experience how small and yet how noble a place he occupies in the world in which he finds himself, coming whence he knows not, going whither he knows not; to find his true place only by accepting his position and by doing the work he finds before him, having faith in his labour only because he labours in the faith that the vast universe is governed by its Creator.

The eye sees by light, but the energy that calls forth the sensation of light existed long before there were eyes to see. The ear hears by sound, but the energy that acts on it existed long before there were ears to hear. Light is not a thing, but an affection; and the command "Let there be light" must have been meant as marking either the beginning of the energy that acts on the organ of sight, or the development of that organ.

It being assumed, therefore, that we are acquainted with the facts of the outer world only by means of our senses (by sight, sound, hearing, feeling, and tasting), it becomes necessary to ask, What do these senses tell us? how do they tell it to us?

The eye tells us the shape, size, and colour of objects; the sense of feeling also indicates these points, but in a much less defined manner. The ear informs us of certain motions or vibrations existing around us; the nose and palate are minor means of doing the same. The eye really tells us only colour; we infer shape and size by a mental process.

But if I stand in a dark room, however full it may be of persons or things, my eyes tell me nothing. It is not sufficient to bring the eye and the thing to be seen in proximity; an agency called *light* is essential. It cannot be too soon or too clearly comprehended, however, that this light is *not* a *thing*, not matter of any kind, but only *motion*. A ray of gas-light falls upon the objects in the room, until now dark, and I am said to *see* everything in it. The simple truth is, that nothing is in the lighted room that was not there when it was dark, but that a certain force has been

communicated to the objects, which sets them in vibration, and that this vibration is communicated to the eye. The nerve within the eye is sufficiently delicate, and the mind of man sufficiently comprehensive, to give to him ideas as to the size, shape, and colour of these objects, the only action outside the eye being motion, the action within the eye being the motion of the nerve, which motion and its mental result constitute light.

It cannot be too strongly or too clearly stated that light, sound, and feeling, all exist *only* in the brain and nerves, and that outside of these there is only motion.

We speak of inanimate nature being cold and lifeless: morally it is so, doubtless, but before we can comprehend Physics we must realise that the whole world and every atom of it is in endless and ever-varying motion; that nothing is absolutely at rest. We must measure the world around us not only by our senses but also by our imagination. A block of stone, however large and solid, must be not only a block of stone, but also an assemblage of atoms of stone, each capable of motion without interference with the character of solidity of the whole. A sheet of glass must be also a regularly-arranged number of atoms of glass, each capable of motion by itself. The distinctions between solid, liquid, and gaseous conditions must be, to our minds, differences of degree only: we must regard all bodies whatever not only, or even chiefly, as bodies, but as groups of bodies. The eye of our imagination must see many things otherwise invisible to us, and the ideas in our mind must be shaped more by our reason than by our senses. When we hear a sound we must realise that a vibrating medium has acted on our ear; a flash of lightning must tell us of gaseous matter in an intense state of vibration. A red-hot poker glows, not with heat, but with the rapid to and fro movements of its atoms. We see in a gas-flame only particles of oxygen and hydrogen moving with a rapidity that is beyond our powers of conception.

There is no fear that this disenchantment will make us realistic and cold. We shall find marvels in nature that will more than compensate for our loss of those hasty, crude, and grovelling ideas that are the first conceptions of ignorance, and we shall have a truer notion of our own position in the world, and of the dignity and responsibility of that position.

SEEING.

If we can once get a clear notion of what "seeing" is, we shall

be on the highroad to a comprehension of light and its phenomena. We say we see a candle-light, a gas-light, a table, a chair, a book, &c. But we see a light by virtue of its own power of acting on our eyes, while to enable us to see a book or a table we require a light in addition. This at once divides all objects called visible into two classes—those that are self-luminous, and those that require to be illuminated.

A lighted candle is placed on a table. Something, either matter or motion, comes from the candle to the eye. Each point of the flame gives off a radiant force, and these, being arrayed in the form of a flame, act upon the eye to give a notion of a flame to the mind. But I not only see the flame; I also see the table, chairs, books, pictures, &c. By what agency? Precisely the same that makes the light itself visible. I stand on one side of the light; on the other is a book and picture. Just as on this side the radiant force from the candle falls on my face, so on that it falls on the book and picture. From the surfaces of these the force is reflected in a second radiation, some of which falls upon my eyes. But the points which radiate this force are now arranged in the form of a book and a picture, and consequently the ideas called forth in my mind are not those of flames, but of a book and a picture. It is important to realise the facts that a flame is a number of points, not an individual object; that these points each radiate force or energy, either as matter or motion; and that these forces, so radiated, proceed quite independently of each other, and are capable of being grouped in innumerable ways so as to present an endless variety of figures. In fact, every object in nature must be considered not as a whole but as a group. A red-hot poker held in the middle of a room before quite dark, will radiate light around, because its atoms are vibrating with immense rapidity, and so scattering around them a force capable of affecting the optic nerve.

A man stands behind me, and I cannot see him. If a looking-glass be placed before me, he becomes at once as visible as if he were in front, but only if some light be present. Let the light of a candle fall on his face; the radiant force of this sets in motion the atoms composing his features, and these radiate force upon the surface of the glass; this in turn is set in vibration and radiates force to my eyes. But the grouping of the vibrating points of the glass is determined by the shape of the face behind me, so that the idea in my mind is that, not of a glass, but of a face. It might be asked, why does not the glass radiate the form of a glass,

just as the face radiates the form of a face? The reply is, that the glass is smooth and hard, the face is rough and soft; the glass reflects ray for ray, sending out as many as it receives, and preserving unchanged the grouping, but the face absorbs some and reflects some, and this alternation and variety of light and shade is what gives us the idea of a human face.

But whether I look straight at the man, or whether I look at him in the glass, I see him by precisely the same means—the radiation from his features of the light falling on them. If there be no glass in front of me, the light from the face behind is still radiated, but it falls, perchance, upon a wall, a book, or a picture, and this partly absorbs and partly reflects the light, grouping its particles anew, so that the varieties of light and shade no longer suggest a face to my mind.

If I have the glass before me, the man behind, and a candle (otherwise invisible to me) shining on his face, I see his features in the glass; but if he hold another glass before his face, I see in the mirror before me, not his features, but an image of the candle. The grouping of the vibrating points is preserved, reflected from mirror to mirror, and to my eyes.

Seeing, therefore, is the effect of a radiant force called light falling upon the eye. A vast number of these rays can enter the eye at the same time, each calling forth an idea in the mind. The number and grouping of these rays that reach the eye depend upon the objects before it. But for the existence of the rays a luminous body is necessary. By a luminous body I mean a body in a state of intense vibration. If this vibration depend upon a force within the vibrating body, then it is self-luminous, as a gas or candle flame.

HEARING.

What I have said of the eye may be repeated of the ear, changing light for sound. The ear is acted upon by the motion of the air in contact with it. But for this motion we require a source of motion. The radiant force that affects the eye is too delicate to act on the ear, and the force that affects the ear is far too gross and rough to act on the eye. But excepting in the degree of intensity, the apparatus and action are very similar.

FEELING.

It is by this sense that we are cognisant of heat, and if we substitute heat for light, the nerves of feeling for the nerve of sight,

we might repeat what we have said of seeing. We feel heat only by the vibration of the objects in contact with our body. I put my hand in hot water and I am conscious of what I call heat—*i.e.*, the vibration of the particles of the water. I take up a snowball, and I am conscious of what I call cold—*i.e.*, the heat or vibration before existing in the particles of my hand is reduced in amount by the parting with some of it to the snow. I do not really feel either the water or the snow; what I do feel is the increase or decrease of vibration in the particles of my hand.

SOUND.

I take a tuning-fork and set it in vibration: it moves to and fro, each time displacing the air by propelling it right or left.

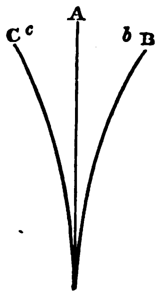


Fig. 1.

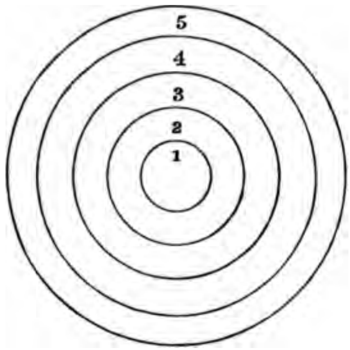


Fig. 2.

This propelling force continues until it reaches my ear, and then it becomes sound. Thus, fig. 1, the fork A sends one vibration towards B and another to C.

A stone falls, or is thrown into water, and sinks; the displaced water rises around it, and moves the air; this motion is continued indefinitely, and if it reach my ear becomes sound.

A small quantity of gunpowder is ignited; the gases produced require very much more room than the constituents of the powder; the air is driven back so as to leave a sphere (1), fig. 2, which these gases fill; this driving force is communicated from (1) to (2), and from (2) to (3), through the air in all directions for an indefinite space; if it come in contact with my ear it becomes sound.

In all these examples of sound, we have motion as the beginning and end; and we may say that sound is derived from motion.

HEAT.

I rub any two bodies together, and they feel warm. I am conscious of this, not by the eye or ear specially, but by the sense of feeling which is distributed over my whole body. I light a fire, and from the combustion of the coal I derive the sense of heat. I stand in the sun, and I feel warm.

In all these there is motion; the sun and the fire communicate a motion to the air, and I receive this from the air. Or it may be a solid instead of a gas that communicates the heat; or even a liquid. If I have a kettle of boiling water, I am conscious of heat whether I place my hand in contact with the solid metal of the kettle, the liquid water within it, or the gaseous steam rising from it. All are in motion.

If C be a heated ball placed on a metal anvil B (fig. 3), and a

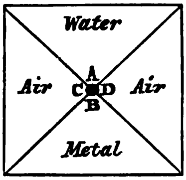


Fig. 3.

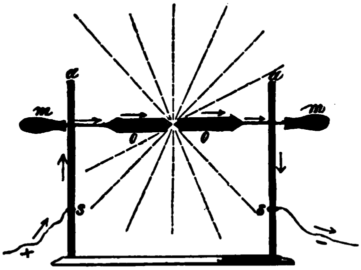


Fig. 4.

vessel of water A be placed above it, the heat passes downward through the solid, upwards through the liquid, and sideways through the surrounding air. That is, the solid, the liquid, and the air will all be set in motion; not motion as a whole, but each particle will move to and fro in vibration.

LIGHT.

I burn a candle, and so produce light. I stand in the sun, and it gives me light. I set in action a voltaic battery and connect with it two pieces of carbon, slightly separated, and again I produce light (fig. 4). This I can do still more brilliantly by increasing the strength of my battery, and so getting the brilliant light of an electric lamp.

In all these there is motion. The carbon of the candle is being converted from a solid to a gas, and this is accompanied by intense vibration. The sun radiates force to us, both as heat and

light. In the case of the electric light, pieces of the carbon are

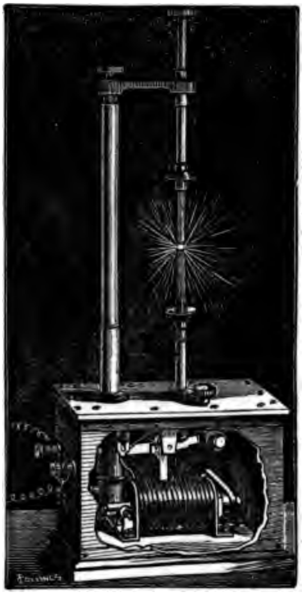


Fig. 5.

being vaporised, and pass from one side of the spark to the other. Light, therefore, is always associated with motion.

ELECTRICITY.

I turn the handle of an electrical machine, fig. 7, and the plate becomes thereby excited, possessing a force which before it had not. Small pieces of paper, feathers, threads, are drawn to and adhere to it for a time. Here is evidently a force capable of producing motion. This force may be conveyed for an indefinite distance by wires, or other good conductors. If I bring near the conductor, a Leyden jar, this force is communicated to the jar in the form of sparks. If I place a wire in the conductor, or otherwise make a point on its surface, the number of sparks is increased, and their intensity diminished, until the discharge assumes the appearance of a glow, as in fig. 9.

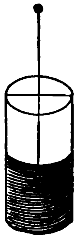


Fig. 6.

How are we conscious of this force being present? Only by

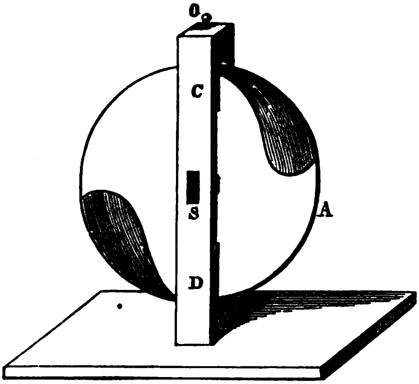


Fig. 7.

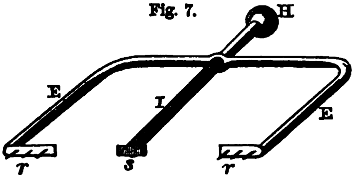


Fig. 8.

the impression made on our senses. We see the bits of paper and threads move to the plate; we see the sparks and the glow, and from this we infer the presence of the force. If I touch the excited conductor, I *feel* a shock: here I am conscious of the presence of the force by means of my sense of touch: the sparks are not only visible, but also audible; here my sense of hearing comes into use.

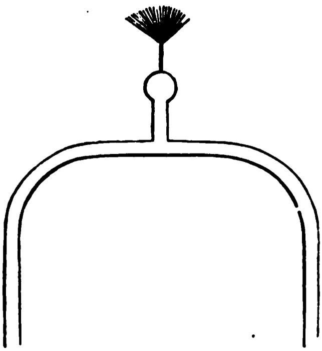


Fig. 9.

But except by means of my senses, I am in no way cognisant of the existence of the force, which is comprehensible by me only through the *motion* it causes.

GALVANISM.

I put together a plate of zinc *c*, a rod of carbon *a*, and some diluted acid; I get a galvanic current. Here I have at command a force capable of producing heat, light, and sound, of decomposing chemical compounds, of moving small magnets. All these effects are phases of *motion*.

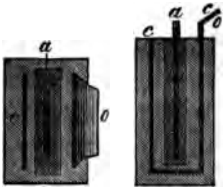


Fig. 10.

This force can be conveyed from one place to another by means of conductors, as is done by the telegraph wires. But the action upon these wires is not appreciable by us, except the motion be within the limits of which our senses can take cognisance. That is, it must take the form of light or heat, or must move some object as a whole. This is really a truism, but most of the statements of physics are truisms, though our technical language prevents our being conscious of this. A boy's magnet moves a steel pen, and we see the motion, because it is on a scale of magnitude which brings it within our powers of sight. A poker is made red hot, and this we see also, because though the motion of the vibrating particles is infinitesimally small, yet its rapidity is enormously great. So that our powers of perception require that the motion shall be either through a considerable space, proportionately to the size of the atoms moved, or else performed with immense velocity and repeated an enormous number of times.

MAGNETISM.

A sixpenny magnet, to be bought at any toy-shop, will attract small iron or steel bodies. A larger magnet has greater attractive force. An ordinary piece of steel may be made into a magnet by being stroked several times with another magnet. A piece of soft iron may be magnetised by putting it near a steel magnet, or by surrounding it by a wire through which an electric current is passing. In all these cases there is motion, but we are not conscious of it; nor can we become so except the motion be of a magnitude or a rapidity that is within the limits of our perceptive powers.

In the magnetisation of a steel bar the atoms move until they are all arranged in a definite direction. But this movement is too small for us to observe. If the magnet move as a whole we

are conscious of its motion, as we are also of the motion of any attracted object.

This is the reason why we can see solids or liquids, but not gases. A lump of ice, and the water into which it may be converted, are alike visible ; but the same ice or water converted into steam becomes invisible, not that the steam is any less real than the water or ice, but because its atoms are too small for our perception.

"Science" has a technical sound; it suggests ideas of thermometers, air-pumps, and diagrams; and it would be well to sometimes translate it into its plain English, *knowledge*. The science of physics means our knowledge of it. Every one has some knowledge of the subject, if it be only that coal burns and water freezes.

It will be useful to bear in mind that the science of physics does not mean a perfect comprehension of the laws of nature, but only our knowledge of them, however imperfect that may be. When we speak of a science being "in its infancy," or of "the present state of science," this language is intelligible at once if "*knowledge*" be substituted for *science*. Of course, the truths and laws of any branch of study, whatever it may be, are the same, and have always been the same, whatever be our knowledge, or want of knowledge, of the subject.

The one idea that I have tried to call up is this—that our knowledge of what passes in the external world is limited by our powers of perception, depending entirely upon our senses, especially the senses of seeing, feeling, and hearing, and pre-eminently on our powers of vision. Science is really not what is, but our knowledge of what is.

A piece of lead placed in a ladle over a good fire will speedily melt—that is, will change the solid for the liquid form. It will still be lead as completely as before; will weigh the same, will have all the properties of lead; the only change being in the inter-relation of its constituent parts. These, instead of being firmly fixed in a mass, so that no one could be moved unless all were moved, are now free to move amongst themselves, and any portion of the whole may be taken away without the remainder being in the least disturbed.

So, in like manner, a lump of ice, placed near a fire, will become first water in its liquid form, and then steam. But its

chemical constitution will remain unchanged; it will weigh the same; it will still be water, whether its state be liquid, as in ordinary water, crystallised, as in ice, or vapour, as in steam.

Figs. 11, 12, and 13, show three instruments by which these fixed degrees of temperature—that of freezing water and that of boiling water—are utilised, to enable us to measure other degrees of temperature by comparison. The thermometric scales here shown are described at page 66.

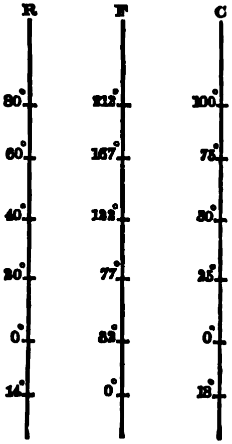


Fig. 11. Fig. 12. Fig. 13.

The fire has, we should say, melted the lead or the ice—meaning that the change from the solid to the liquid, and from the liquid to the vapour condition, had been brought about by the influence of the fire. But there has been no contact between the two; no portion of the material of the fire has entered into the solid body in order to melt it; no chemical change is caused by the action of the fire. Still the body exposed to the fire becomes warm by means of the heat received from the fire. The action and the result is as if the fire emitted some agent (of such ethereal nature as to be capable of penetrating the most dense substances) that, entering into the lead and the ice, forces their constituent particles asunder, so that they become individual bodies, each acted upon independently by gravitation. This is really the nature of the change from the solid to the liquid condition. A lump of stone placed in any vessel will preserve its own shape, whatever may be that of the vessel; but if the same stone be ground to sand, and these sands poured into any vessel, as a basin, they will be grouped together so as to take, collectively, the form of the vessel. So also a lump of ice would stand in a basin, but as it melted into drops of water these would take the form of the basin even more readily than the sand-grains, because of the greater smoothness of their surfaces. The finer the grains of sand, the more readily would they be impressed with the form of the containing vessel, and, so far, the more nearly would they approach the condition of a fluid.

The melted lead would occupy more room than it did when solid; the steam would occupy very much more room than the

water which produced it; and generally, as bodies of any kind become heated, they expand and increase in size. It would seem as if the ethereal agent emitted by the fire entered between the particles of any substance exposed to it and pushed them apart. In the first stage of this expansion, the repulsion effected by the heat is not sufficient to overcome the cohesion of the particles; and the body, though increased in size, is still solid. This stage continues until the repulsion, owing to increased heat, just equals the cohesion of the particles. This is the limit between the solid and liquid conditions. The least increase of heat induces the second stage, in which the repulsion is stronger than the cohesion, and the body becomes liquid.

If more heat be added, the liquid may eventually be rendered aeriform—*i.e.*, the repulsive force will become so powerful as to break up the cohesion of the particles of the drops of liquid, and these will be driven asunder. In this, the third stage, the body will become invisible, by reason of its constituent particles being individually too small for perception by the human eye. The steam made from any given quantity of water will weigh exactly the same as the water. A pound of ice will make neither more nor less than a pound of water, and may be converted into steam that will still weigh exactly a pound. So that the expansion and contraction caused by the addition or subtraction of heat must be regarded as only an increase or decrease of volume or size, not of quantity. If heated, a given body will expand and occupy more room, but will not have any addition of material. Conversely, if cooled, it will shrink into a smaller space, without losing any portion of its substance.

Snow swept from the top of a house to the edge of the roof would fall into the street. If it were melted the water would fall, the same as the snow; if it were boiled, the steam so produced would, instead of falling, rise into the air—that is, the same matter which under one set of circumstances falls, will, under others, rise. Thus, a cork will fall in air, but will rise in water. But the snow, the water, the steam, and the cork, all have weight, and the cork only rises in the water, because the water, being heavier, forces its way beneath it, and so pushes it up.

When we say that the cork, ice, and water all have weight, we mean that when free from all other constraint they will fall to the ground—that some power (apparently in the earth itself) draws them all towards the centre of the earth. What this power is, no

one knows; and the name **Gravitation** given to it is only the expression of the observed effects, not of their cause.

A cork, a piece of lead, and a feather, if let fall in a space entirely vacant—*i.e.*, an absolute vacuum, such as in a large jar from which all the air has been pumped—will all fall to the bottom with equal rapidity. The feather will fall "dead" to the ground, instead of floating about, just as the cork or the lead. But if we put two things, such as cork and water, in the same vessel, the water will fall to the bottom, and, being liquid, will take the form of the vessel and occupy all the lower part of it, driving up the cork. It would be wrong to say that the cork rises through water (as it would seem to do if water be poured into a vessel in which a cork is placed); the cork passively resists the force of the water, and is driven up by it.

If a piece of lead and a piece of cork be set free in a tub of water, the lead will sink to the bottom and the cork rise to the top. Why? Because the lead is heavier than the water, and the cork lighter. But what is "heavier" and "lighter"? We say that lead sinks in water because it is heavier than water—that is, any given bulk of lead (say a cubic inch) weighs more than an equal bulk of water, and any given bulk of cork is lighter than an equal bulk of water. But "heavier" and "lighter" are here used as names for effects rather than for causes. If we take a piece of lead, and another of cork, equal in size, and weigh them against each other, the lead will weigh down the cork—that is, the attraction of the earth for the lead being greater than its attraction for the cork, the lead will be drawn down and the cork consequently drawn up.

But why has the earth greater attraction for lead than for cork? It cannot be imagined that this depends on the nature of the material, as if it were a case of chemical attraction. But if we consider that the attractive force of the earth is a mechanical force, it may be supposed that it is exerted alike on all matter; and that every atom of matter, of whatever kind, is pulled towards the earth with equal force. If in lead the atoms be compressed more closely together than in cork, then any given piece of lead will be drawn with more force than a piece of cork of equal size, because there will be more lead than cork to be drawn down.

Thus, if we take equal bulks of water and iron we shall find that the weight of the iron is nearly three times that of the water. This is because the atoms of the iron are more closely packed together than those of the water. Thus, if there be a hundred atoms

of water in a given bulk, there will be in an equal bulk of iron three hundred atoms; and since we suppose the earth's attraction to act with equal force on each atom of matter, the weight of the water will be only one-third of that of the iron—*i.e.*, the force which the earth will exert on the iron will be to that which it exerts on the water as 300 to 100, or 3 to 1.

Even the most solid substance must be considered to be made up of atoms of matter, not in absolute contact, but kept together by mutual attraction. Just as the earth attracts a stone, so every particle of matter must be considered to attract every other particle. A substance is said to be solid when all its particles are so held together by attraction as to require some force to separate them. But it must not be supposed that these atoms are in absolute contact in any substance, whether solid, liquid, or gaseous. For example: If a vessel be partly filled with water, and then filled completely by spirits of wine, it will be found, on mixing the liquids well together, that they occupy less space together than separate. This could not be the case if their ultimate particles were in actual contact. So also in the case of metals; by means of hammering, their constituent atoms may be compressed into a smaller space, which could not be done unless there be some space vacant between the atoms of which they are composed.

In considering the phenomena of our ordinary experience, we must remember, and allow for, the important effect of the atmosphere. If we look at fish swimming in a glass globe, we should allow for the effect of the water upon the sight; and the effect of the air in which we move about is at least as important. Fig. 14 shows how a ray of light, A *o*, has its direction changed when passing through water, to *o o'*, and afterwards, when passing again to air, reverts to a direction *o'* B, parallel to A A'. By it are affected all rays of light passing through it, the weight of all bodies, and the intensity of all sounds.

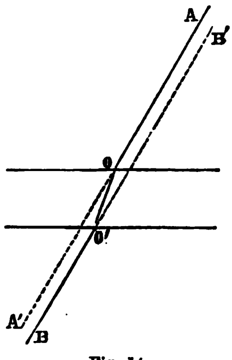


Fig. 14.

This example will enable us to realise somewhat the way in which almost every thing is affected, in some way or other, by the pressure of the invisible yet ever-present atmosphere in which we live, and which is necessary to our life.

Fig. 15 shows the succession of colours as the velocity of the light increases and its wave-length decreases. Thus a vibration occurring less than 39,000 times per second will be invisible, as represented in the diagram by shading, decreasing in intensity as it reaches the limit of visibility. As the vibrations increase in number and decrease in wave-length the colour passes from red to orange, orange to yellow, &c., not suddenly, but by imperceptible gradations. There are no lines of demarcation whatever throughout the spectrum : everything is gradual. As the vibrations become still more numerous, the effect upon the eye becomes so continuous that no mental perception is possible, and darkness is the practical result.

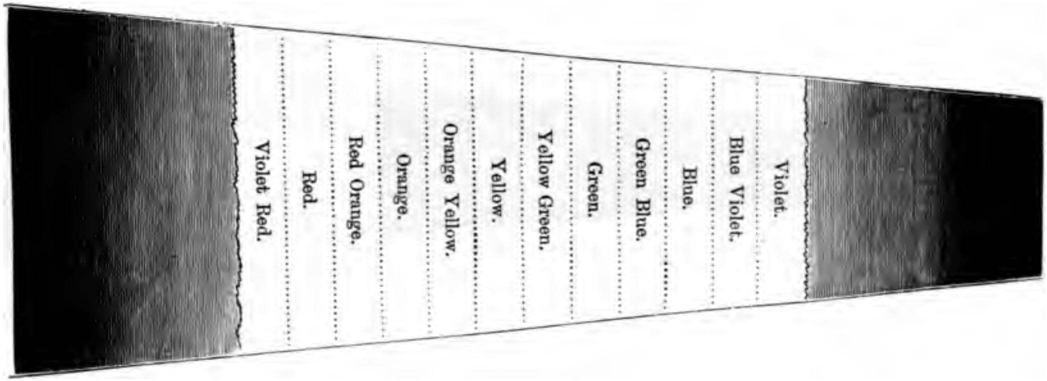


Fig. 15.

[To face p. 16.]

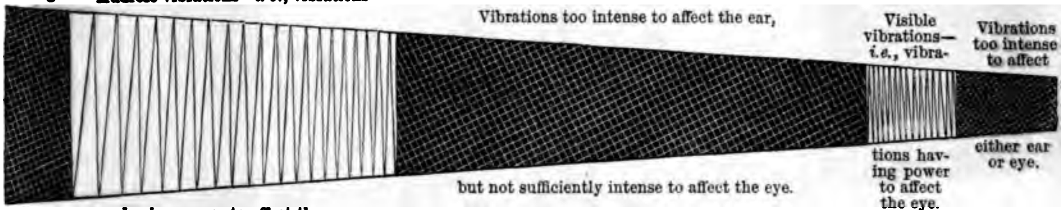


Fig. 16.

This diagram does not assume that the medium of vibration for sight is the same as for sound, but that the number of vibrations in a given time and space are much greater for light than for sound; and, conversely, that the wave-length is much greater for sound than for light.

If the number of vibrations be too great to enable the ear or eye to distinguish one from another, the result is, practically, insensibility to the vibration altogether—just as when we walk on the flat top of a large table-land we are unconscious of being above the ordinary level, having no means of comparison.

ACOUSTICS.

SOUND.

(1.) **Introduction.**—A bell rung under water has been heard nine miles distant; a whisper can be heard through a small tube at the distance of half a mile or more.

A sound heard at a considerable distance is seldom heard singly. Thus a bell rung at one end of a long tube gives a double sound, as does the report of a gun, or a blow with a heavy hammer.

Here are two facts: One, that sounds can be heard at considerable distances through tubes; another, that sounds so heard at a distance are usually double.

What is a sound? We say that we hear with our ears; but what is hearing? What do we hear? How do we hear it?

Just as we can see only when light comes in actual contact with our eyes, so we can hear only when the air, whose vibration causes what we call a sound, is in actual contact with our ears. A bell is rung—*i. e.*, its clapper is set in motion and strikes the side of the bell. This vibrates and sets the air in motion; this motion is communicated from one particle of air to the next, and so on until some particle strikes upon the tympanum, or drum, of the ear, and so produces in the brain the sensation of a sound.

When a gun is fired, the great expansion of the gases generated by the combustion of the powder drives away the air, which immediately recovers its equilibrium and re-enters the barrel of the gun. This vibration of the air is communicated to the surrounding particles on all sides, and thus the sound is conveyed to the ear.

Sound, then, is simply an impression conveyed to the brain by the action of vibrating air on the ear, just as sight is an impression conveyed to the brain by the action of light on the eye. There are, however, important differences between the two. Light acts across a vacuum—sound cannot; light travels with almost inconceivable rapidity—sound, in comparison, but slowly.

Sound is conveyed by any medium—solid, liquid, or gaseous;

and by solids better than by either liquids or gases. This will explain the double sound just mentioned. Thus, if a long bar of iron be struck at one end loudly with a hammer, a person at the other extremity will hear two sounds—one carried to his ear by the vibration of the air, and the other carried by the vibration of the iron. Sound will pass along a solid iron bar, or the iron of a pipe, just as water would pass through the pipe. So also, when a gun is fired, the sound is heard twice by a person some distance off; being carried by the air, and also by the vapour contained in the air.

But even if the iron and the air, the air and the water, each carries its own sound, need there be two sounds? Will they not be heard together so as to make but one? No: for their rates of travel differ, and so the ear gets first one message and then the second. I have just mentioned that light travels rapidly, and sound, in comparison, but slowly. This is why we see the lightning before we hear the thunder, since the light takes so short a time in comparison with the sound to reach us. Whatever be the distance of the storm, we see the lightning-flash almost at the very instant, but the sound of the thunder will take some time to reach us: and we may, by measuring the time between the flash and the roll, tell how far away is the storm; for sound travels at the rate of 1100 feet every second, so that if we hear the thunder five seconds after we see the lightning, the sound has travelled five times 1100 feet. But light travels nearly 200,000 *miles* per second, so that however far away the storm, the distance causes no delay in our seeing the flash. Just in the same way, but at much smaller intervals, we hear the same sound twice—first by one medium, then by another. There is an exact parallel to this in the case of light. It is easy to see the same object double —*i. e.*, to get two rays of light coming from it and reaching the eye, but in different directions; so it is possible to hear the same sound twice, if there be two mediums of vibration, in which the sound travels at different rates. In air, sound travels 1100 feet per second; in water, 4900 feet; in iron, 17,000 feet.

Light and heat may be reflected—*i. e.*, have their direction changed. So may sound, but not in such small compass. Once, in walking through a long arched passage, near one end of which an itinerant band was playing, I heard the sound of the music twice in almost equal power—once when passing the players, again when near the opposite end of the passage. Just at that spot the sound was almost as audible as close to the men, though between it was scarcely distinguishable.

This will explain what is called echo. A person looking at a light on a table, in a room having a mirror on the wall, might see two lights; or rather, see the same light twice—once in its place on the table, and again in the mirror, and apparently behind it. So with an echo: a sound striking against a large smooth surface is reflected and may be heard twice; once directly through the

air, and again through the vibration reflected from the surface, as from a rock or wall.

Sounds may be so shrill as to be inaudible; our ears being only capable of taking cognisance of vibration between certain limits of rapidity and slowness. In distinguishing between sounds, we speak of their **pitch**, their **quality**, their **loudness**. All sounds arise from vibration of the air. The more *rapid* this vibration, the higher the *pitch;* the *greater the quantity of air* set in motion, the *louder* the sound: the *quality* depends on the nature and form of the body set in motion.

If I take a piece of ordinary string and shake it loosely in the air, I get no sound; but if I put my foot on one end, and holding the other in one hand, stretching the string tightly, I strike it with my finger or a penholder, I get a buzzing noise from its vibrations. If I shorten the tightened part, by holding only a portion of it stretched, I get a sharper noise, and this sharpness, or shrillness, increases as I shorten the string. If I fasten a ball to the end of the string and swing it slowly round, I hear nothing; but as I increase the speed of the revolutions I also increase the sound, and it gradually becomes audible.

By shortening the string, or by increasing the speed, I increase the number of vibrations in any given time, and this increases the sharpness, or pitch, of the sound.

(2.) **Sources of Sound.**—Just as the eye is the only organ of sight, and the palate the only organ of taste, so the ear is the only organ of sound—*i. e.*, the only means by which we can become cognisant of it. This perception arises from the air in the immediate vicinity of the ear being disturbed so as to impinge upon the tympanum—*i. e.*, a membrane that closes the orifice of the ear, separating the air without from the air within. This tympanum (the action of which is exactly that of a drum-head) being struck, the air enclosed is set in corresponding motion, and the auditory nerve, being acted on by this motion, conveys to the brain the idea of sound. If this be done but once, the result is simply a *sound;* if it be continued irregularly and confusedly, the result is *noise;* if it be continuous at regular intervals, the result is a *musical note.*

Since sound thus depends upon the motion of air in the neighbourhood of the ear, anything which so sets the air in motion is a source of sound. Thus I strike the table with my hand, knock two books together, ring a bell, break a window—in fact, move any object rapidly and continuously—and I so set the air in motion. But the sound may be too low to be audible; not that it is not a sound, but that our organ of hearing is too imperfect to give us the perception of all sounds. Some are too low and some too high for our perceptive powers.

(3.) **Limits of Sound.**—It has been proved by experiment

that the vibrations of the air upon the ear must be at least at the rate of sixteen per second for the production of a continuous sound—*i.e.*, the impression does not last more than $\frac{1}{16}$ of a second. On the other hand, the vibrations may succeed each other so rapidly that no sound is perceptible. Theoretically there is no limit to the gamut of sounds, but our sense of hearing is capable only of appreciating the middle of the scale, some sounds being too low and others too high for our perception.

A precise parallel exists in the case of light. A ray of refracted light produces a spectrum, only the middle portion of which is visible to our eyes.

(4.) **Form of Sound-Waves.**—Just as a lighted candle in the centre of a room radiates light to every part of the room, so a sound produced at the same point would be audible at every position which a person would take. It is common to speak of light, heat, and sound as travelling in straight lines, but it would be, I think, more theoretically true to describe the motion as spherical, the source of the light, heat, or sound being always at the centre of the sphere. Just as an onion is covered by several concentric coats, so we may imagine a lighted candle or a source of sound to be surrounded on all sides by concentric shells of air. We need not imagine these shells to be in any sense distinct or divided from each other except by the effect of the vibration during its existence. Each shell will be, of course, greater than any one within, and less than any one without it; and from this it follows that the sound will become feebler and feebler because of the greater amount of air to be set in vibration.

Let a small collodion balloon be exploded at a given point. The "explosion" means that by the action of light upon the contents of the balloon a chemical change takes place, and that the new substance requires more room than the old one did. In consequence, the air is forced back on all sides to make room for it. The extent of this compression depends upon the active force remaining after some portion of it has been counteracted by the resistance of the air. Suppose the globular space marked (1)—fig. 17—to be occupied by the contents of the balloon after the explosion, then the radius of this sphere (the sphere being represented in the diagram by a circle) will be the measure of the intensity of the produced sound and of the amplitude of the sound-wave.

The air that did occupy this space will be driven into the surrounding space (2), and in like manner will produce a compression there, and a consequent action upon the space (3). In this way each shell of air will be compressed by the intrusion of the air from within it, and will by its resistance drive back the inner shell of air, while it is itself driven into the space of the shell without, to be again driven back into its original position.

In this way there is a constant series of waves of condensation and expansion, the length of the waves being governed entirely

by the original force, and the intensity of the sound (generally called "loudness") depending likewise upon the same cause. It is sometimes said that the intensity of the sound depends upon the amount of this compression, but it might be more correct to say that the amount of compression and the intensity of sound are both results of the same cause, the force with which the compression is made.

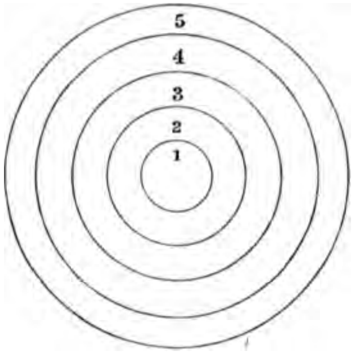


Fig. 17.

Thus, this alternate compression and expansion continues through the air (the thickness of the shells, *i. e.*, lengths of the waves, continuing the same, according to some theories), until its further progress is stopped by some obstacle. If this be a large flat surface the sound is reflected—if it be irregular, the small inlets will be filled up, just as the waves of the sea enter all the bays and inlets of a coast.

Supposing such a sphere of vibration to come in contact with my head, my ear is to it just as an inlet on the coast to the sea. The spherical contour is broken, and the vibrating air, entering the ear, impinges upon the tympanum. Supposing a number of persons to be arranged so as to form a sphere, or any portion of a sphere (at the centre of which the source of the sound is placed), they will all hear the same sound at the same instant, with the same intensity, supposing all the organs of hearing to be equally sensitive. This must necessarily be the case, since the same shell of vibrating air strikes upon all the ears.

But if two persons are at different distances from the source of the sound, neither the times nor the intensities of the sound will coincide. The more distant auditor will have to wait until the vibration reaches the sphere of air in which his ear is situate, and since this sphere is larger than the sphere in which the nearer person is, the sound will be weaker—*i. e.*, the vibration will be weaker. In the chapter on *Radiation* I have discussed the question, whether these spherical shells of air are really all of the same thickness, as is usually described to be the case.

(5.) **Intensity of Sound.**—This depends entirely upon the force with which the sound-wave impinges upon the ear, and this depends entirely upon the original force which caused the sound-wave. The greater this force, the greater the radius of the first, and of every succeeding, sphere of air set in motion.

Thus the greater the force resulting from the explosion of the balloon, the greater would be the space (1), and each succeeding space (2), (3), (4), &c. The greater also the velocity with which the particles would move to and fro. So that the greater the initial force, the greater the distance through which each particle moves, and the greater the velocity with which it moves.

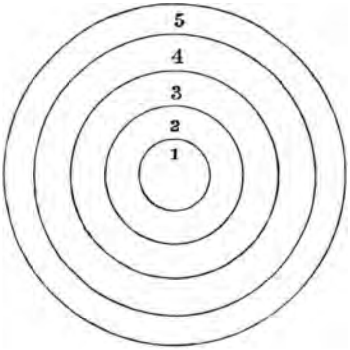


Fig. 18.

The force with which a weight falls depends on the distance through which it has moved, and its velocity. A ball striking the wall depends for its force on its distance and its velocity. And generally any moving body strikes another body, with which it may come in contact, with a force proportionate to its distance and velocity.

But while in the case of a falling body the force becomes greater with the distance through which it moves, it is the reverse with a body whose motion depends, not upon gravitation, but only upon an initial force imparted at starting. In this latter case the greater the distance the less the remaining force.

So that we have to consider three things in estimating the intensity of sound—*i. e.*, the force with which it falls upon the ear:

(1.) The *amplitude* of the sound-wave—*i. e.*, the distance each particle moves;

(2.) The *velocity* with which the particles move;

(3.) The *distance* which the sound has travelled.

This last is quite distinct from the motion of each particle, and depends entirely upon the distance between the origin of sound and the ear. Thus, if I put a watch first close to my ear, and then on a table at the other end of the room, the *distances* are very different, but the *amplitude* of the sound-wave and the *velocity* of each particle of air, in moving to and fro, are the same—*i. e.*, the watch does the same work in either case.

Practically, the intensity of a sound is the force with which the ear is struck by the particles of air in contact with it. If the ear were at the limit of the first wave (1), it would be struck with greater force than if at the limit of the second wave, and generally the greater the distance the less the sound, because of its diffusion. The law of diffusion for sound, as for light and heat, is inversely as the square of the distance—*i. e.*, at twice any given distance a sound is reduced to one-fourth, at three times that distance to one-ninth.

In the same manner the intensity is *increased* as the square of the increased amplitude or velocity, and these are increased by the same cause, the increase of initial force.

(6.) **Nature of Sound.**—To show that sound is this alternate compression and expansion of successive spherical shells of air (supposing air to be the medium), and not a continual movement forward of any part of it, several illustrations may be given. Thus, to show that sound, like heat and light, is a transfer of *motion* and not of *matter*, it might be enough to point out the many parallels in heat, light, and electricity, the exceeding probability that sound is a phenomenon of like nature, and the absence of any facts to suggest any other theory.

Watching the tide rising or falling on the coast, it is difficult to realise that the waves are but the risings and fallings of the water, and not the transfer of some definite quantity of water from far off to the land. But careful notice of floating objects, such as pieces of wood, bottles, &c., shows that the water does but rise and fall. In the same way the passing of a brisk wind over a field of corn illustrates the transfer of motion, but not of matter, very beautifully and completely. There is, however, this difference, that in the transfer of heat, light, sound, &c., the original impulse is given to the first wave only, and transmitted from wave to wave, while the wind that passes over a field of corn acts directly as well as mediately upon each stalk. But it is still certain that, however much appearances may suggest the idea of an actual transfer of matter across the field, it is but a transfer of motion, each part rising and falling in succession.

But it would be absurd to urge that sound is probably a vibration because heat and light are supposed to be vibrations, and that heat is also supposed to be so because sound and light are; and, finally, that light is such because sound and heat are probably the same. It is necessary either to prove the probability, if not certainty, in one case at least (when we might be permitted to urge analogy as a reason), or to adduce satisfactory reasons in each case separately.

In the case of sound it may be pointed out that the conditions of increased velocity and intensity are such as might be expected to obtain if the theory of vibrations were true, but are not such as fit a theory of emission. Thus a sound is conveyed more rapidly through water than through air, and still more rapidly through iron, which could scarcely be the case if actual transfer of matter were required. Again, the intensity of a sound is increased by commencing in a dense atmosphere, which would retard rather than increase the force of matter actually in transmission. Also, any number of persons at the same distance from any source of sound hear it with equal intensity whatever be their position, provided no obstacle intervene. This is what would be expected if the sound be considered to be a vibration, but is not explicable

upon the assumption that sound is a transfer of actual matter. Sounds travel many miles, and the size of a sphere, the radius of which is several miles, renders it scarcely possible that particles of matter proceeding from a central point could diverge so regularly as to form a spherical shell so large, or that particles so numerous could start from one point with such regularity as to form an unbroken shell of constantly-increasing size.

We know that sound does proceed in all directions from its source, and that in the largest theatre or church it has never been noticed that any two persons could hear while a third between them could not, unless, indeed, some obstacle intervened.

Then, if it be imagined that sound is actually a transfer of matter, the question must occur, What is it that is transferred? I ring a bell in the middle of an empty room, so that there are present but the bell and the air. Any hypothesis that the blow of the hammer upon the bell sent particles of the bell itself flying through space is scarcely worth discussion, especially when it is considered that the directions of sound seem in all cases to be quite independent of the law of gravitation, proceeding in unerringly straight lines in every direction. And it seems almost as incredible that the particles of air in immediate contact with the bell should be set in motion for an indefinite distance through an atmosphere made up of particles exactly like themselves in every respect.

Lastly, there is the fact that any number of particles, however great may be the number, is not indefinitely great, and cannot fill up a constantly-increasing space. Thus a slight stroke of a clapper upon a bell displaces a certain amount of air. This is made up of a certain definite number of atoms of oxygen and of nitrogen. Assume these to be set in continuous motion, and not to be impeded in any way by the surrounding atmosphere, they could not increase in size, and so must separate from each other, radiating from a common centre, in a limited number of straight lines. These lines would diverge more and more from each other, so that only persons whose ears happened to be in the direction of one or other of them would have any perception of sound conveyed to them, while those between would be totally unaffected.

So that if a bell were rung in a large room, having a row of men standing ranged around against the wall, only one of every eight or ten or twenty, according to the size of the room, would hear it; while if the bell were slowly turned round while being struck, the sound would pass to each man in turn. Just as if a lantern, having but a few holes in its sides, were turned round and round, when the light-rays would pass over each man in succession, and each would in succession be first lit up and then in darkness.

Therefore it seems very improbable, if not impossible, that sound can be either an emission of particles of matter, or a transmission of a few particles of air; while the theory of a transfer of vibration

not only accounts for all the facts, but is in accordance with the calculations made upon the data that force is indestructible and transferable.

(7.) **Reflection of Sound.** — I ring a small bell at *a*, the focus of A, so lightly that its sound may be inaudible at C, half way between the reflectors; yet at *b*, the focus of the reflector B, at twice the distance A C from A, the sound may be distinctly heard. If I place my ear at C, it receives only the sound-rays coming directly from the bell at *a*, and I hear nothing; but at *b*, all the rays falling from *a* upon A, and thence transmitted to B, are collected together, so that their united effect is to produce a sound that is audible.

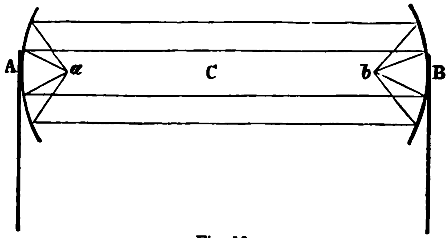


Fig. 19.

At any point between the two reflectors there are as many rays passing as meet at *a* or *b*, but they are so far apart that the ear cannot take cognisance of them all at once. There is here a precise parallel to the difference between a solid and a gas, that makes one visible and the other not so. A small piece of ice is visible to me because its atoms are so close together that my eye can see them collectively; but the same ice converted into steam would be invisible to me, because its constituent particles, being isolated, would not give out light enough to affect my eye with the sensation of sight.

So with the rays of sound proceeding from A to B, the effect of each isolated ray is not sufficient to give to me the sensation of sound; but when they are collected at *b*, their combined effect is sufficient to produce this effect. If I place a conical reflector, such as a smooth glass funnel, with its open end towards A, at the point C, so as to collect and converge all these rays, my ear, if placed at the small opening of the funnel, will hear the sound of the bell just as at *b*. All that is required is that the sound-rays shall be brought together in sufficient number to affect the auditory nerve. The further I am from the source of sound, the greater is the number of rays that must be collected to make the sound audible.

If I transpose the bell from *a* to *b*, and my ear from *b* to *a*, the result is precisely as before. In each case the sound seems to come to me from the mirror, and not from the bell itself. Really it does both. It comes from the bell by way, as it were, of the two mirrors, but its direction being so completely changed by

the two reflections, I have no suggestion as to the real position of the bell itself, and no guide as to the direction in which the sound has come, except the converging rays from the second reflector.

(8.) **Echo.**—An *echo* is a special case of reflection where sound is reflected on a large scale. Thus at Enville, near Stourbridge, one of the walls surrounding the gardens of Enville Hall, the seat of Lord Stamford, is at one place built in a curve. One day this summer, walking at the side of this wall, I suddenly heard, quite distinctly, the voices of some friends who were at some distance behind, and which had been until that moment quite inaudible. The fact was that at that moment we were both similarly situated with reference to the wall, so that the sound proceeding from one point, after radiation, was re-collected by convergence at the other point.

The curve *a b* of the wall is doubtless that of an ellipse, and the points A B are the foci. Any person speaking at A or B would be more distinctly audible at B or A (*i. e.* at the other focus), than at any intermediate point. In the particular case of the wall which I have just mentioned, the existence of the echo would not be suggested except it chanced that a person was at one focus and heard a sound produced at the other. In the case of persons talking, the speakers might be many times at one focus, and no one at the other to hear them; and *vice versa*, a person might be at either focus when no sound was at the other to be heard. Unless the wall were known to be of the required curve (in which case the discovery of the foci would be a mere matter of calculation) there would be no suspicion of the existence of an echo until chance revealed it.

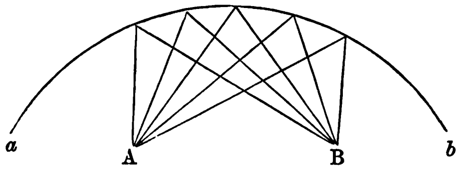


Fig. 20.

(9.) **Compound Echoes.**—Some echoes are compound—*i. e.*, any given sound is repeated several times. This requires a more complicated relation between the position where the sound is produced and that where the echoes are heard. But this may happen in many ways. There may be several elliptical curves having the same foci, but in this case the echoes would be almost synchronous, for the interval of time between two such echoes would be scarcely appreciable. Thus the times required for the sound to travel from A to B (fig. 21) along the roads A *a* B, A *b* B, and A *c* B, would be nearly alike in most cases. Yet if the points *a*, *b*, and *c*, were considerably distant from each other, the echoes would be quite distinct; and if one were near the hearer and

another afar off, there would be also a perceptible difference in the tone and intensity of the echo.

But a greater variety of tone, distinctness of sound, and a gradually-increasing sweetness, are found where the echoes are produced by more complex means. Fig. 22 represents an imaginary case of this kind. A and B being the positions of the person producing and the person hearing the sounds, the variety of echoes would be caused by the variety of routes by which the sound passed from A to B. Thus some of the vibrations will be reflected direct from *a* to B; others falling near *a* will be reflected to *b*, and thence focused at B; others, again, reflected from A to *a*, from *a* to *b*, and from *b* to *c*, will be also brought to a focus at B. This subdivision may be imagined to be carried to any extent. It might be replied that it is almost impossible that two points could be so related as A and B are here supposed to be. But however true this may be, there are compound echoes. One at Woodstock Park repeats from seventeen to twenty times. One at Killarney repeats the same sound many times, with a most pleasing variety of tone. In the Alps are more than one such instance. The most favourable condition would seem to be that two large and tolerably flat surfaces should be parallel to each other; and this is to be found in most mountainous regions, where great clefts or gaps are not unusual. Here a sound falling on one side would be reflected and re-reflected an almost endless number of times. The complete enclosure afforded by two high rocks would prevent the general diffusion of the sound at once; and it is easy to imagine that some of the vibrations will be, in most of the reflections, sent to any spot favourably chosen.

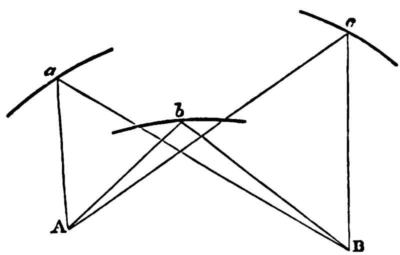


Fig. 21.

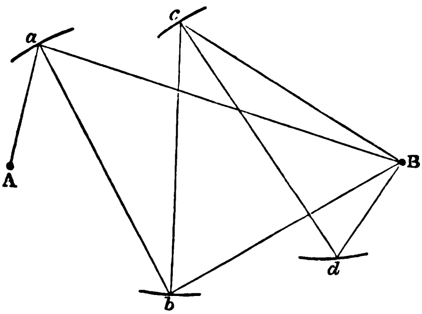


Fig. 22.

(10.) Refraction of Sound.—We have just seen how, by

reflection, we can convey sound from one place to another almost at will. We can do the same by another method. If it be required to transfer a sound from A to B (fig. 23), we can do so, using reflection as a means, by placing two curved reflectors, one outside each point A and B, so that these points are the foci of the curves of the reflectors. But if, instead of using the reflectors, I suspend *between the points* a small balloon filled with some gas *heavier than air*, I shall find that the rays of sound falling on one side will be converged on the other.

Thus a small bell rung at A so softly as to be inaudible at B, may be heard at that point if a balloon be suspended between the two points. One man at A strikes the bell softly; another at B receives no intimation of the sound, because the rays of sound diverge from A, and so few reach B that no sound is there perceptible. But when a balloon of thin material, filled with carbonic acid gas (or any other *heavy* gas), is placed between, the rays of sound are converged—*i. e.*, bent from above downwards, from below upwards, and from right and left to the same central point. Now if the balloon be so placed that this point shall be at B, the rays falling on the balloon from A will be all, or nearly all, re-collected at B. In this way sound may be transferred from A to B by refraction, just as heat or light may be.

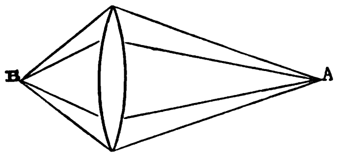


Fig. 23.

So that the general laws of reflection and refraction are the same for sound as for heat or light.

The balloon of heavy gas performs for sound exactly the same office that a convex lens of glass does for light, or a rock-salt lens for heat. In each case the rays (whether of heat, light, or sound) fall upon a medium thicker in the middle, and gradually decreasing in thickness towards the edge, and of greater density than the air. In each case this convex body acts as a double prism (or as two prisms base to base) on the rays falling on it—that is, it refracts them towards the base of the prisms, so that the lines on each side, being all refracted towards the same point, ultimately meet at that point.

The *form* of the refracting medium is the same in all cases, but the material is different in each. Rays of light pass through glass much more completely than through a balloon of gas or a rock-salt prism. Rays of heat pass much more readily and completely through a rock-salt lens or prism than through any other substance.

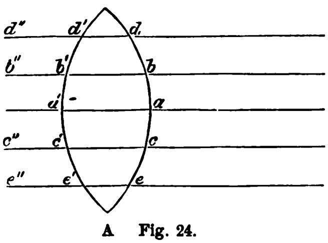
The balloon of carbonic gas refracts the rays of sound because the velocity of sound-vibrations through carbonic gas is less than through air. But why should it be so? For precisely the same reason that walking through water is more tedious than walking

through air, and through mud more so than through water. With a given muscular exertion I can walk a given distance—say twenty yards—through air. I have at each step to force my legs through the air, though the resistance of this air is so slight that I am not conscious of it. The same muscular exertion will not enable me to walk the same distance through water, because the resistance is so much greater; and a still less distance would it take me through mud, or any substance still more dense than water.

Imagine a row of men marching at the same rate across a field, and coming to a circular pond of water. Suppose also that each man is unable to put forth any extra exertion, but must be retarded by any difficulty that comes in his way. In this case, the man who has to cross the pond at its widest part will be more delayed than the others, and the delay will gradually diminish as we pass from this man to the man at the extreme edge who has the least water to wade through.

The passage of sound-rays through a balloon of carbonic acid is precisely analogous to this. The ray that passes directly through the centre will be retarded most, and those passing through the edges least; while intermediate rays will be retarded more or less, according as they pass nearer to the centre or the edge. More force is required to set in vibration any given quantity of a heavy than the same quantity of a light one; and as a consequence, the same force will set in vibration a greater quantity of a light gas than of a heavy one.

Let A represent a quantity of heavy gas (say carbonic acid), which must necessarily be confined in a balloon or covering of some kind. A series of rays of sound falls in parallel order upon it at *a b c d e*, and each is delayed in a degree proportionate to the distance through which it has heavier work to do. The sound-ray *a* can only continue its course by setting in vibration all the carbonic acid in its passage. The same must be done by the other rays, *b c d e*. In each case the retardation will be, not the whole amount of force, but the amount required to move the given volume of heavy gas over the amount required to move the same volume of light gas.



A Fig. 24.

By the time that the ray *d* has reached to *d′*, and so got fairly through, the ray *b* will be about two-thirds, and the ray *a* about half way, through the heavy gas. The ray *c* will be also about two-thirds through, and the ray *e* will have arrived at *e′*, corresponding to *d′*.

Again, by the time that *b* has arrived at *b′*, the ray *d* will be

on its road past d' towards d'', while the ray a will be still struggling, as it were, towards a'. So with the rays c and e. At last, when a has finally reached a', b will be at b'', and c at c'', while d and e will have passed d'' and e''.

So that the rays that were not only parallel, but abreast, will now form a curve d'' a' e'', and this will prevent their continuing parallel; for the action will be the same as if so many streams of water were flowing into an empty basin. Wherever an empty space occurred between two streams, they would flow sideways to fill it up. So the rays b and c would each turn aside towards a, and for the same reason d and e would likewise be converged.

The action of each ray upon the others would be as though the men just spoken of as wading through water were chained together. The tendency would be to draw the extremities of the row of men together; and it must be borne in mind that there are really no *rays* of sound, but a wave, proceeding from some point or surface, and gradually broadening in all directions—such a wave falling upon a balloon or lens has its widening checked by the retardation of its central portion, and its extreme edges are thus brought together until they finally meet at some point.

(11.) **Velocity of Sound.**—The rate at which this motion travels varies from many causes—the density of the medium, its elasticity, and its temperature as affecting its density and elasticity. But as a convenient approximation, and a number easily remembered, the velocity of about 1000 feet per second may be taken as the normal rate at the surface of the earth, supposing air to be the medium.

We have seen that sound, travelling through a heavy gas such as carbonic acid, moves more slowly than through a lighter gas such as ordinary air; this is because of the greater force required to move, or set in vibration, the heavier gas; or rather, because of the smaller quantity of the heavy gas that any given force can set in motion as compared with the lighter, the times being equal.

The velocity of sound through air at 0° C. has been determined as being 1090 feet per second. It may be noticed that 0° C.—*i.e.*, the zero of the centigrade thermometer, identical with the freezing-point of water—is chosen as the standard temperature for many formulæ in all branches of physics. This is from its being not only a point in the range of temperature easily understood, but also one easily obtained.

But the simple statement that sound travels through air at 0° C. at the rate of 1090 feet per second, declares a fact much more easily expressed than understood; and it is still more difficult to comprehend fully the method of measurement, and the obstacles in the way of an accurate result.

(12.) **Methods of Estimating the Velocity of Sound.**—Two methods of estimating the velocity of sound have been adopted. One, that of actual experiment, without which no result could be safely accepted; the other, that of calculation: that is, one method is to estimate what it ought to be according to the theory of its formation; the other, to estimate what it really is according to fact. If these two investigations, pursued independently, give results that are corroborative, there is very strong ground for the presumption that the truth has been arrived at, at least approximately.

The estimate of the actual velocity of sound by experiment is obtained by means of sounds sent along given distances, the times of the transit of which are accurately noted. Thus a gun being fired at a given spot, an observer stationed at another given spot notices the exact interval of time between the instant when the flash of light reaches his eye and the instant when the sound reaches his ear. Thus two points being taken at the distance of exactly a mile apart, a gun is fired at one of them, or, to insure greater accuracy, a gun is placed at either point. The light will travel through a mile of space in about $\frac{1}{200.000}$ of a second, and for all practical purposes, even for these of exact measurements, this may be disregarded, and the observer at either point may safely calculate that he perceives the flash at the very instant the gun is fired. But it would be some five seconds before the sound would reach his ear, and these five seconds would be the actual velocity of sound. This seems very simple, and very easy of execution, but it is exceedingly difficult for any one not actually engaged in researches of this kind to imagine the difficulties in the way of arriving at an accurate result, the numberless sources of error, or the delicacy of the apparatus and minuteness of calculation required for the investigation.

Two men, A and B, are stationed a mile apart. A fires a gun, and B, noting the flash, measures by his watch the time between the arrival of the flash and the sound at his post. What can be simpler? Therefore the velocity of sound is one mile in five seconds, or twelve miles per minute. True, apparently, even to demonstration; but if the same two men were to repeat the experiment daily for a month, choosing all the conditions so far as they could, so that they should be the same, it is more than probable that no two of the results would agree in every detail. A puff of wind (to say nothing of a breeze), the presence of more or less vapour in the air, would be quite enough to alter the result; and these alterations would themselves vary with the force of the wind and the amount of vapour. The barometer and thermometer would also have to be consulted, and their variations allowed for. And when all the meteorological conditions had been taken into account and duly verified, and the necessary corrections made, there would be the necessity for the verification of the distance from A to B—the exact measurement of the assumed mile. No

one but those who have attempted to measure with extreme accuracy any given distance can readily believe the numberless difficulties there are in the way of a correct result being arrived at.

Shall I measure the distance with a tape or string? If I lay it along the ground, the ups and downs of the surface will destroy all hope of correct measurement. If I stretch it from one pole to another, no way is known of preventing it hanging more or less in a festoon. Shall I use a rigid rod of wood or metal? I may this way, by extreme care, measure a mile of *surface length*, but cannot find two points exactly a mile apart. If I attempt, by means of a rod, to measure a mile through space a little above the surface (so as to escape the errors caused by the irregularity of the ground), I soon find the task more hopeless than ever. To mark the intermediate points; to insure measuring in a straight line; to prevent the successive measurements from overlapping or falling short,—each of these presents an almost insuperable difficulty. Add to this the element of incorrectness arising from the fact that any change of temperature really alters the length of my bar of metal or wood, and the task at once becomes utterly hopeless.

How, then, can we measure a given distance? Only by reference to some fixed standards, such as the sun or stars, and by the most elaborate and careful calculation, can we hope to do so simple a thing as to measure a mile of ground. It is unnecessary to explain this process here; and I have, I hope, said enough to suggest the difficulty of accurate measurements of any kind, and the patience and humility required for the prosecution of any natural science. It is this that makes the study of Physics so great an element in education; so useful in forcing upon us the knowledge of how feeble are our powers as compared with the world of wonders in which we find ourselves; and also, even more strongly, how wonderful are those powers to enable us to understand so much.

(13.) **Causes affecting the Velocity of Sound.**—To return to the velocity of sound, I said just now that it was about one mile in five seconds under ordinary circumstances—*i. e.*, about 1100 feet per second. How can this velocity be increased or retarded? To answer this question it is necessary to consider to what the velocity of sound is due—what it is that causes the transmission of a sound.

I have tried to explain how a sound is produced by the air being driven out of a certain space so as to cause a compression on the surrounding air on every side. This compression extends to a certain distance, depending upon the force of its origin. This is called a *sound-wave.* The force that compresses the air so far is considered to pass on, causing another compression of equal extent. This is a second *sound-wave.* The force still continues, causing a third, fourth, and fifth sound-wave; in fact

it continues indefinitely, just as any force does, until it is destroyed by some opposing force, either suddenly or gradually.

It may be asked, Why does the wave end at any given distance? Why not continue for an indefinite distance, only weakening gradually? This is just what is the result, *practically*. But there is the very decided limit of the first wave, at the point where the vacuum of air (not an absolute vacuum) ended. The space through which the air was driven—the space filled up by the expansion or vibration that rendered more room necessary—determines the length of the wave.

The velocity of sound is the speed at which these waves are generated; and this depends upon two points—the *density* of the medium, and its *elasticity*. Any increase of density *decreases* the velocity of sound, any increase of elasticity *increases* it. Sound travels more slowly in a dense than in a rare medium, and more quickly in an elastic than in a non-elastic medium.

Any increase of density generally increases also the elasticity of a body. Thus, any body whatever being compressed becomes more dense and more elastic; so that compression decreases velocity by increasing density, and increases it by increasing elasticity. But the increase due to increased elasticity does not always equal the decrease due to increased density. In the case of air it does so; so that in air of any given temperature the velocity of sound is always the same, because density and elasticity increase together and counteract each other.

Generally sound travels in liquids more rapidly than in gases, and in solids more rapidly than in liquids. This is contrary to what would be at first expected, since liquids are more dense than gases, and solids more dense than liquids; and this would be expected to decrease the velocity of sound, and in fact *does so*. But the elasticity of solids is greater than the elasticity of liquids, and that of liquids greater than that of gases, and generally this more than counteracts the decrease arising from increased density; so that a sound-wave passing from air to water has its velocity increased from 1130 feet per second in air at 20° C. to 4800 feet per second in water at the same temperature, and to 4030 feet in lead, 8553 feet in silver, and 16,822 in iron—all being at 20° C.

In passing from water to lead, both being at 20° C., the velocity falls from 4800 feet to 4030 feet per second. This is because the density is increased more than the elasticity, and lowers the velocity more than the increased elasticity raises it. Lead is remarkable for its want of elasticity.

Notice that I have to specify the temperature. Any increase of this increases the velocity by tending to decrease the density, but usually also decreases it by decreasing the elasticity.

Water at 15° C. conveys sound at 4714 feet per second; at 30° C. it conveys it 5013 feet. Here the increase, owing to decreased density, is greater than the decrease, owing to decreased elasticity.

In hydrogen, at 0° C., the velocity of sound is 4164 feet per

second, while in oxygen it is only 1040 feet, and in air 1090 feet. This illustrates clearly how density decreases velocity. Hydrogen being the lightest gas allows the greatest velocity. In oxygen, a heavy gas, the velocity is less than in air, and in carbonic anhydride, a heavier gas, the velocity is only 858 feet per second. In gases, increase of density is not compensated by increase of elasticity in anything like the degree that it is in liquids or solids. Hence the velocity varies so much more in accordance with the density.

In iron at 20° C. the velocity is 16,822 feet per second; in iron at 100° C. it is 17,386 feet; and at 200° C. it is only 15,483 per second. So that increase of temperature from 20° to 100° increases the velocity by decreasing the density more than it decreases the elasticity, while the increase from 100° to 200° decreases the velocity by decreasing the elasticity more than it decreases the density. In wood at 20° C. the velocity is 16,677 feet, at 100° C. it is only 5297 feet, and at 200° C. only 2987 feet. Here again the elasticity is decreased more than the density by increased temperature.

Another phase of the increase of velocity arising from change of temperature is somewhat singular. If C represent any vibrating body, such as the prong of a tuning-fork, then A C will represent the air compressed by the movement of C towards A; and C B will represent the air expanded from the same cause. Consequently the temperature of A C is raised by compression, and the temperature of C B lowered by expansion. We have seen that the velocity of sound does not vary from any increase or decrease of temperature, because the increase or decrease of density just balances the increase or decrease of elasticity; so that neither the increase of temperature in A C, nor the decrease in B C, would be expected to produce any change in the velocity of sound.

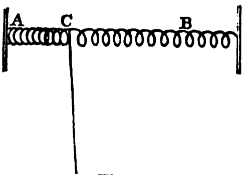


Fig. 25.

But we must distinguish between a change of temperature in the whole body of air, and an interchange between two portions of the body, the average temperature remaining the same. The space A C is warmed at the expense of B C. This makes no change in the average temperature of the whole space A B, being merely a transfer from one side of C to the other.

If the temperature of the whole body of air be raised or lowered, the velocity of sound in it remains the same; but if the amount of heat in the air be *collected at intervals*, the result is an *increase of velocity, both* in the condensed portions, such as A C, *and* in the rarefied portions, such as B C. That is, the velocity of sound in air is increased by the effects of compression and expansion arising from the passage of the sound-wave. In the con-

densed space A C the density is increased, and also the elasticity, by the heat arising from compression. In the expanded space B C the density is diminished, and also the elasticity, by the loss of heat arising from expansion. But there is also the increased elasticity due to the compression, and this is not counteracted by any further increase of density. Consequently the velocity of a sound-wave (which increases with any increase of elasticity) is increased.

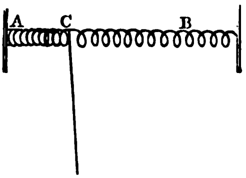


Fig. 26.

To sum up these somewhat complicated facts. The space of air A C is compressed. This results in increased elasticity and in increased temperature. This increased temperature causes a further increase of elasticity, but this is counteracted by increased density, so that the elasticity is increased more than the density, and consequently the velocity of sound is increased.

In the expanded portion of air B C the density is diminished, and the elasticity also. But the expansion arising from the removal of external pressure differs from that arising from increased temperature. The one *allows* the air to diffuse itself, the other *compels* the diffusion. But practically the air *does* expand, and the expansion acts as elasticity in increasing the velocity of sound.

Finally, the velocity of sound in air is not increased or diminished by change of temperature of the air *as a whole—i.e.*, by the addition of heat or the abstraction of it; but it is increased by the change of temperature in the portions of the air as they are compressed or expanded.

(14.) **Conservation of Force in Sound.**—But it may be observed, this being the case, the air being driven a certain distance and no farther, because the force is not sufficient to compress it farther, what force is there to carry the vibration farther? Whence the force to cause a second sound-wave? The usual reply to this is to say that the same force that creates the first sound-wave creates the second and all succeeding waves—that *force* never ends—that a sound sent up in the air, where it could pass away into space, would continue for indefinite time and space. To illustrate this it is customary to show that any body in motion coming into contact with a body at rest, is brought to rest, or at least retarded, while the whole, or at least a part, of its force is transferred to the body with which it comes into contact. Thus a man running round the corner of a street is stopped by coming into contact with another man who is standing still. The force that he loses is transferred to the second man, who is more or less in danger of being thrown down, and has to exert muscular force to counteract the impulse he receives. I throw a stone from the street at a window. The stone is brought to rest inside the room

much sooner than it would come to rest if no obstacle was in its way. The force which the stone thus loses is the force that breaks the window. Two railway trains come into collision ; the force that each loses is the force that damages the carriages.

One illustration frequently given on this point is that of placing a row of marbles close together at rest, and shooting another marble at the first of the row. The result is, that the marble set in motion is brought to rest (unless it proceeds, with diminished force, sideways), and that the force it loses passes from marble to marble, the last of the row being moved more than any other by means of the impetus thus transferred.

In the same way it is considered that the force which creates one sound-wave creates also a second and a third, continuing indefinitely until some obstacle comes in its way. It might be asked, if the force can create an infinity of sound-waves, one after another, why is the first sound-wave limited ? Why is there not one vast sound-wave ? Practically this is really what there is ; but since it has the same marked characteristics at equal (or very nearly equal) distances, it is customary to consider the intervals between each of these as a wave. This gives a convenient means of description and measurement that would not otherwise exist.

. Reverting to the elements of a sound-wave, I will take a continuous and regular wave for the purpose of description, since I can then the better compare the successive conditions of each part of it.

I take a large tuning-fork and set it in vibration; it moves to and fro within fixed limits, and would continue to do so for an indefinite time but for the resistance of the air, which acts in opposition to the motion of any object in it. I move the prong of the fork from A to B. To do this I must use force enough to overcome the resistance of the particles of the fork, and also to push back the air that occupies the space through which the fork moves. On releasing the fork at B it moves back at once to A, but does not stop there. Just as the pendulum of a clock would behave under similar circumstances, it passes to C, as far on one side of A as B is on the other. What force carries it to B ? I apply force to move it from A to B. The elasticity of the metal undoes this work, and carries it back from B to A. Why should it not rest there ? Why continue in motion ? Why stop at C ?

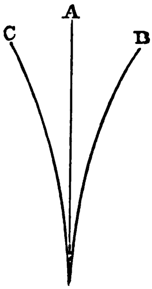


Fig. 27.

To answer these questions let me take another illustration. A weight, say 56 lb., is resting on a table that is just strong enough to support it, and which would break if another pound were added. I fasten a cord to this weight, and pass it over a pulley fastened to the ceiling. Pulling at the cord, I raise the weight from the table, say ten feet, and then let it fall

by its own weight—*i.e.*, I let the force of gravitation undo my work, and replace the weight on the table. But the table is now broken. By what force? Not the weight of 56 lb., for it would support that. Not by the force of gravitation, for that would only replace it on the table—would only undo the work that I did. It is really the force that I used in raising the weight that breaks the table.

I bend a bow by means of the string fastened to its ends. Releasing the string, I allow the bow to resume its former condition. But, in addition to this, it will send an arrow to a considerable distance. The force with which it does this is exactly proportioned to that which I expend in bending the bow.

Upon such facts as these is based the theory that *force* cannot be destroyed; that, though a vibration, a motion, it is as indestructible as matter. Thus it is considered that a stone once set rolling would roll for ever, were it not for the friction of the ground and the opposition of the air. In like manner the force that generates one sound-wave continues to generate others, until its progress is stopped by some obstacle that it has not power to overcome.

But it might be replied to this: Given a stone that twenty men could lift; let the twenty men each put forth the requisite force, but individually and successively, not collectively; the stone will not be moved an inch. What becomes of the force? Is it not entirely wasted? Yes; wasted, but not destroyed. By means of very simple machinery the twenty items of power might be so collected and combined as to really move the stone as completely as if the whole twenty men were working together; nay, by the same machinery, one man, by doing successively the whole twenty shares of work himself, may move the stone just as the twenty men could.

Again, let a bow be bent by the whole strength of one man, and the string be then fastened, so as not to allow the bow to straighten. If released at the end of an hour, or even a day, it will be found to possess still the force originally conferred on it, and the arrow will be projected as far, and with the same velocity, as at first it would have been. Force may be gradually dissipated, or wasted, but does not decay. A handful of corn found in the coffin of an Egyptian mummy, and sown, after an interval of some thousands of years, germinated and produced other ears of corn, just as if but a few months old. The vitality of the corn might easily have been destroyed, but could not decay. The life that a tread might have crushed endured for centuries in the darkness of its stone tomb, testifying that the vitality that has power over all things else has none over itself. It may be killed, but cannot die. So with *force;* it may be wasted, but it cannot waste: it may be cast to the winds, but it is eternal.

To revert to the question, Why should the prong of the fork continue in vibration? I move it from A to B, and release

it. It returns to A, and passes on to C, A C being equal to A B, or very nearly so. Just as the bow when released not only straightened itself but propelled the arrow; just as the weight, when let fall, not only returned to its place, but broke the table that had previously sustained it: so the prong of the tuning-fork, when released, not only returns to its former position, but is bent nearly as far on the other side. The force that bent it from A to B, now deflects it from A towards C. But its deflection is not *quite* equal to A B, because in moving from A towards C, it has to overcome the resistance of the air through which it moves, so that it moves only from A to *c*, just short of C.

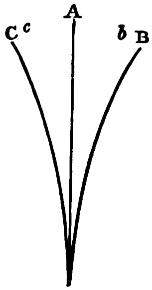


Fig. 28.

The distance of *c* from C is the distance which requires the force that is spent in moving the air out of the way in the passage from A to *c*. Force cannot be destroyed, but neither can it do more than its own work: it cannot do two things at once.

But the prong having arrived at *c* is again brought back to A by its elasticity. It is now in its original position, so that the imposed force has really done nothing. This same force now moves it to *b* not quite so far to the right of A as *c* is to the left, and for the same reason as before, that the air has to be removed from its path. Again the elasticity straightens the prong; again force bends it. Each time air has to be displaced, each time therefore force is used up, each time the deflection is less and less, until at last, when the whole of the force has been spent in moving the air, and consequently none is left to move the fork, it comes to rest.

What becomes of the *force* about which so much is said? Does it merely "beat the air?" It does this, and more than this: it moves the air each time to make way for the fork, and this *pulse* or motion of the air is called a sound-wave. The same force that makes the first wave makes a second, and so on until, *if the air so in motion come in contact with the ear*, a sound is produced.

If the fork had been set vibrating in a vacuum, it would have remained in motion much longer, but it would have produced no sound, for the whole of the force would be effective in moving the prong, since there would be no air to move out of the way; consequently there would be no sound-wave, and therefore no sound.

(15.) **Generation of Sound-Waves.**—The sound-waves thus produced by the driving back of the air from any given space are, as has been explained, *spherical*, extending on all sides from the origin of the motion. It is, however, very difficult to follow this sphere in the mind, and to see it as a whole, yet divided into

parts—*i.e.*, to notice especially the movement of any portion of it, and yet keep before us the view of the whole. Nor is it necessary to do this, provided we recollect that there is a sphere of motion ever enlarging in size, ever diminishing in rapidity.

Fixing my mind upon some one small portion and watching its progress, I watch it as it gradually widens out in all directions, just as a fan does in one direction only.

Thus the prong of the tuning-fork moving from A to B pushes back the air to B. This causes a pulse of air to be sent in the direction A B. Meanwhile the prong moves back from B to A causing a vacuum which is instantly filled up by the return of the air it had previously driven away. This causes a return of the air, which is now set in motion towards A from B. The prong again moving from A to B compresses the air in the direction A B, then again returning to A, causes a second return-current towards A. In this way a constant ebb and flow of vibration is caused by the alternate compression and expansion of the air on either side of the prong.

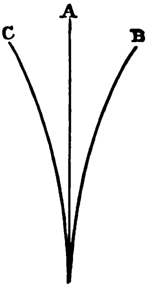


Fig. 29.

A very clear idea of this action may be obtained by fastening two springs to a small rod, and moving it to and fro. Thus A and B are two springs fastened, one on either side, to a rod C. When I move C to the right, A is expanded and B compressed; when I move it to the left, B is expanded and A compressed. This expresses exactly the condition of the air on each side of the prong of the tuning-fork. If this movement to and fro be done rapidly, there will really be two contrary motions in the same spring at the same time: that is, before the compression imparted to one end of the spring has reached the other end, its expansion will have commenced; and again, before this expansion has reached the whole length of the spring it will receive another impulse of compression.

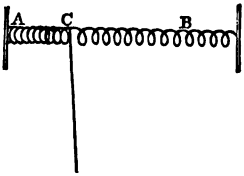


Fig. 30.

But the whole of each impulse, whether of compression or of expansion, will exert its full power. A *pulse*, as it were, will pass throughout the whole length of the spring, and if the air be considered to be represented by the spring, we shall see how a compressive force imposed upon one portion will pass through the whole body of air until it comes into contact with some solid body.

If, now, I move the spring once, I send one vibration, and one only, through its length, followed by a return-pulse, as the air recovers its equal distribution. If I pass a whip or a stick

swiftly through the air I cause in the same way one vibration to pass and return. Notice, however, that each particle of air moves but a small distance, and then returns to its first position.

If I move the prong to and fro, or move a stick or whip to and fro rapidly, I produce a continuous series of vibrations, each of which passes through the whole body of air in which it occurs; so that the air is constantly in motion, each particle vibrating to and fro, but never going far from its original position. Thus I suppose a column of air enclosed in a pipe to be set in motion in this manner.

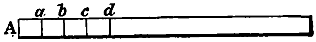


Fig. 31.

A given particle is at *a*, and is set in motion towards *b*, by a wave of compression communicated at A. By the time this particle has reached *b* the wave of expansion reaches it, and it immediately returns towards *a*; but having reached that point, is at once urged again to *b* by a second wave of compression, only to be again drawn back to *a* by a second wave of expansion. Each particle throughout the column is thus moved to and fro, *b* to and fro from *b* to *c*, *c* to and fro from *c* to *d*, and the *pulse* or vibration moves through the whole length of the pipe, though each particle of air moves but a short distance from its first position, to which it continually returns.

(16.) **Perception of Sound.**—In this way a series of impulses is given to each particle of air, so that any solid body at any given point receives a continuous series of very slight blows. If this body be the drum of a human ear, the result is the perception of a continuous sound. This perception is owing to the nature of the ear, not that of the vibration. The air falls on the ear just as it would upon any other body in its place. The auditory nerve, which, placed within the ear, receives these impulses, conveys the impulse to the brain, and the perception of sound is in this way produced. So that, however far may be the distance from which a sound proceeds, the one essential condition is that there shall be, *throughout the whole distance*, a vibrating medium. Any vacuum between the origin of a sound and my ear prevents my hearing it.

(17.) **Continuance of Sound.**—I have spoken of the vibration of a tuning-fork as producing upon the ear the effect of a continuous sound—*i.e.*, continuous so long as the vibrations of the fork continue. What will be the effect of a single tap upon a non-vibrating body? The fork continues to vibrate because it is elastic. If, with the same amount of force, I strike a marble mantelpiece, or a table, what is the result? Not a continuous, but a single sound. Only one impulse is sent through the air, only one sound-wave falls upon the ear, only one instantaneous perception is produced. If I *continue* the tapping, what

is the result? Neither a single tap nor a vibration, but a series of vibrations, one for each tap.

What, then, is the difference between the series of taps upon the marble, and the series of taps made by the vibrating prong upon the air? Why should one series give a continuous sound and the other not? Simply because of the difference in rapidity. I cannot by my hand tap on the table with sufficient rapidity to produce sounds so that each shall succeed the preceding one before it has died away. But the tuning-fork does this; and so the consecutive sounds of the vibrations succeed with such rapidity as to produce a continuous sound.

But if I can get a series of tappings to succeed each other with greater rapidity I do produce a continuous sound. Thus, if I hold the edge of a card or piece of metal against a toothed wheel, so that the teeth of the wheel, when rapidly revolving, strike successively against it, I get a continuous sound, because the conditions are now the same as in the case of the vibrating fork. The sounds succeed each other so rapidly that before one has ceased to affect my ear the next begins to do so.

(18) **Musical Notes.**—If I have two wheels, each having the same number of teeth, and revolving with equal speed, but one having the teeth at equal distances, and the other having them at unequal distances, this difference in the arrangement of the teeth will cause a marked difference between the sounds produced when a card or slip of wood is held to the teeth. The regularly-arranged teeth will, by their impact, produce a vibration that will neither rise nor fall in pitch, and will have that regular and pleasant sound which we describe by the term "musical." It will be found, upon further consideration, that this continuity and regularity are the essentials of a musical note. The difference between one such note and another depends upon the number of sounds, or vibrations, in a given time.

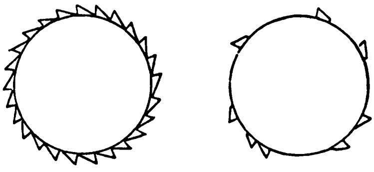


Fig. 32.

It is therefore only in the regularity of its sound-waves that a musical differs from a non-musical note; it is this regularity that makes it musical. Such a note depends for its pitch, its intensity, its duration, upon precisely the same circumstances as other sounds. The tuning-fork will illustrate all these points. The *pitch* depends upon the number of vibrations per second; the more numerous the vibrations the higher the pitch: the *intensity* depends on the length of the sound-wave; the more the fork is deflected the louder will be the sound—*i.e.*, the greater the force

communicated to the fork, the longer will be the sound-wave, and the greater will be the sound into which the force will be converted: the *duration* of the note depends upon the time the vibration continues; the longer the fork is in motion the longer will the sound be audible.

The effects produced by the vibration of a metal prong are also produced by the vibration of a string or wire. I take an ordinary violin-string, fasten one end to anything and tighten it either by passing the other end round a screw (as in a violin) or by fastening a weight to it. The string being thus tightened, I set it in vibration either by drawing a bow across it, or drawing it sideways with the finger and releasing it suddenly. The string by its vibration produces a series of sound-waves just as the tuning-fork did. The *pitch* of the sound thus produced depends upon the number of vibrations; the greater this number the more numerous the sound-waves. The more numerous the sound-waves in a given time, the more rapidly must they succeed each other. The more rapid this succession, the greater the effect produced upon the auditory nerve. We express this effect by calling it the *pitch* of the tone, which may vary from a growl to a scream; which may descend so low as to be below our powers of perception, or rise so high as to be above them.

(19.) **Pitch of Musical Sounds.**—The particular string I use gives forth a particular note. I tighten it, by screwing it up, or by increasing the weight that depends from it. I now set it in motion as before, and find I produce a shriller note. I restore the original tension, and find I have reproduced the original note; the pitch is as at first. I unscrew the string somewhat, or decrease the weight, and now the string gives forth a lower note; the pitch is lowered. By again restoring the original tension I again reproduce the original pitch. And, speaking generally, the same string, stretched to the same degree of tension, will always give the same note when set in vibration. The greater the tension of the string, the more rapidly will it return to its first position, when released, and consequently the more rapidly will it continue to vibrate. The more rapid the vibration the higher the pitch; and therefore the greater the tension the higher the pitch.

I now shorten the vibrating portion of the string, which I can easily do without shortening the string itself. This is what a violinist does when he places his finger on the string. When the string is *open*, the whole of it vibrates, but when the finger is placed on it, only the part between the bridge and the finger vibrates. In some such way I shorten, practically, the string, and then, as before, set it in vibration. The note produced is higher in pitch than when the whole string vibrates. I shorten the string still more; the pitch of the note is still higher.

In this way it may be shown that the pitch of a note increases

as the length of the string decreases, and decreases as the length of the string increases. The shorter a string is, the more forcibly will it be straightened, and therefore the more rapid will be the vibrations: the more rapid the vibrations the greater number of them in any given time, and therefore the higher the pitch of the note produced.

A glance at the sounding-board of a piano will show what a great difference there is between the wire of the highest note and that of the lowest, and that there is a continuous increase of length from one extreme to the other. A harp is also an example of this; the highest notes are produced by the movement of the shortest strings, and the length increases continuously from the string of the highest to that of the lowest note.

(20.) **Causes affecting Pitch of Sounds.**—If I stretch two strings side by side, of equal thickness, length, and with equal degrees of tension, they produce but one sound practically—*i.e.*, the two sounds are so exactly alike that they blend into one louder sound; the ear is unable to distinguish one from the other. Also, if I shorten one of these strings to exactly half the length of the other, there is a remarkable resemblance between the sounds produced by the vibrations of the two strings. The sounds, though not identical, are so completely harmonious, that the ear, though able to detect the existence of two sounds, cannot distinguish one from the other. The same result will, of course, be attained by either halving one of two equal strings, or by doubling it. So long as we have two strings, one double the length of the other, but equal in all other respects, we shall have two sounds so nearly alike as to be completely harmonious and practically inseparable by the ear. But though I get these two notes, called an *octave*, either by shortening or by lengthening one of two strings, I do not get the *same octave* by either process. Thus I have two strings exactly alike in all respects, and each producing a sound which I will call C. Now, if I shorten one by half its length, I get a higher note, which I will call C′; this is the octave *above* C. If I lengthen one of the strings and make it double its former length I get a lower, deeper note, which I will call C, ; this is the octave *below* C. In either way I get two notes separated by an octave, but in one case it is C and C′, and in the other C and C,. The lower note of one octave is the higher note of the other.

Therefore the pitch of the produced note is raised if the string be shortened or if it be tightened. But this is no more than saying that the vibrations are more numerous. If they be more numerous the pitch is said to be higher—*i.e.*, the effect on the nerve of the ear is more intense, because the waves succeed each cther in more rapid succession. And this is the case when the string is either shortened or tightened, for in either case the elasticity of the string is increased, and it returns to its first position with more force and rapidity.

Again, the pitch of a note is affected if the string be thickened, or have its thickness lessened. Thus on a violin, where the strings are all of equal length, and where it is yet essential that there should be a variety of notes, this variety is attained by having strings of various thicknesses. An ordinary violin has four strings, one called the G string, because when the whole string is in motion it gives the note known as G. By shortening the vibrating portion of the string, it is made to give other and higher notes. Practically, the notes A B C and D are produced in this way. The next string, a thinner one, is tightened until its whole length gives the note D—*i. e.*, this string begins where the other leaves off. From this second string, shortened as before, we can get the notes E F G and A. The third string, a still thinner one, is tuned to produce A when *open*, and B C D and E when shortened. The fourth and thinnest string produces E when *open;* and by being shortened, F G A B, and any higher notes that may be wanted. The diagram (fig. 33) shows the arrangement of the four strings.

It must be borne in mind that the one string G (the thickest) will give all the notes usually produced by a violin, but the arrangement of the four strings gives greater purity of tone, and greater practical convenience.

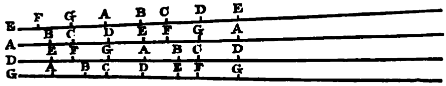


Fig. 33.

Greater purity of tone, because the notes lie closer together as they rise in pitch, and therefore any slight inaccuracy of position in the finger gives greater error in a high note than a lower one on the same string. Greater practical convenience, as giving two octaves of notes within reach of the fingers without moving the hand as a whole.

From this we see that strings of equal lengths do not give the same note unless they are of the same thickness. So that, other things being equal, the thicker string gives the lower note, and the thinner string the higher—*i. e.*, the motion of the thicker string is the more sluggish, because of the greater mass to be moved.

We now know, therefore, that the note to be given by the vibration of any string—*i.e.*, the number of its sound-waves—depends upon its *tension*, its *length*, and its *thickness*. But if increased thickness cause a less number of vibrations because of the greater weight to be moved, the same result should follow from the substitution of a string or wire of a more dense substance but of the same thickness; and we find this to be the case. If we have on a board several wires of equal lengths and thicknesses and stretched by equal weights, but of different densities—say of silver, aluminium, (lighter than silver), and platinum (heavier than silver)—it will be found that the same variety of notes will result as if the strings were of the one material, but varied in thickness,—*i. e.*, the greater mass in the same thickness has exactly the same effect

upon the notes as the greater thickness. And this is but natural. If a horse could draw a hundred blocks of any light substance, he could draw one block of some heavy substance which would be of the same weight as the whole hundred others; and, as far as the horse was concerned, it would be immaterial whether he drew a large number of the light or a small number of the heavy blocks. So with the vibration of a string resulting from any given force. The heavier the string the less rapid the vibrations, and it is the same whether the increase of weight arises from an increase of material in the way of thickness or in the way of density.

(21.) **Octaves of Sound: Scales.**—We have seen that the whole string and the half of it produce harmonious sounds. What will be the result of dividing the string or wire into three equal parts? If I sound the longer part, two-thirds of the whole, I get a sound that makes three vibrations while the whole string makes two. The two notes thus produced by strings in the ratio of 2 to 3 are (excepting the two already mentioned) the most pleasant when heard together. This *interval* (to use the musical phrase) is called a *fifth*, and represents just the difference in tone between any two strings of a violin. The lowest string is the G string, and the notes are named thus—

G, A, B, C, D, and the intervals are:—

Between	G and A,	. .	a second, or two notes.
„	G and B,	. .	a third, or three notes.
„	G and C,	. .	a fourth, or four notes.
„	G and D,	. .	a fifth, or five notes.

The following figure shows that each string on a violin is tuned so as to be a fifth above the next lower.

Thus between G and D, between D and A, and between A and E, there is in every case an interval of a fifth. This has the advantage of giving the power of producing these intervals to the best advantage in harmony. But it also means that whatever number of vibrations the highest string makes, the next lower makes two-thirds as many; the next lower two-thirds of this second number; and the lowest two-thirds of the third number.

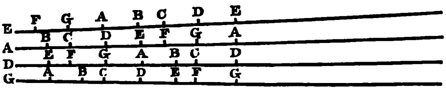


Fig. 34.

Thus the E string vibrates 640 times per second; the A string 426 times, or $\frac{2}{3}$ of 640; the D string 284 times, or $\frac{2}{3}$ of 426; and the G string $\frac{2}{3}$ of 284, or 189.

Then, by reducing the length of my string one-third, I get a tone one-fifth higher; but what of the other portion, one-third of the whole? This, if set in vibration, will give the octave of the new tone (the one produced by the two-thirds of the whole string), because its length is the half of it.

If the note of the whole string be C, the note of two-thirds of the string will be G above the C, and the note of one-third will be the G above this.

I now shorten the string by one-fourth—*i.e.*, I divide it into two parts, one being three-fourths and the other one-fourth of the whole. The longer part will make four vibrations, while the whole string would make three, and will consequently give a higher note. If two strings in the ratio of 3 to 4 as to length be now sounded together, the harmony will be less pleasant than that of the octave (produced by equal strings), or of the fifth (produced by strings in the ratio of 2 to 3), but still not unpleasant. The interval so produced is called a fourth, because it embraces four notes; thus F is the fourth of C, and the interval contains the notes C, D, E, and F. I may continue to divide my string into four, five, six, &c., equal parts, and in each case the note will be of higher pitch—*i.e.*, the shorter the string vibrating, the more numerous the vibrations. Let the string be of such a length, thickness, density, and tension, that it will make 256 vibrations per second. Such a vibration will produce a note very near to the one usually called C—written in music as 

I may now divide this string in many ways, or (what has the same result) take other strings of the same thickness, density, and tension, but shorter in various ratios.

From the whole string I get 256 vibrations per second and the note C 

From half the string I get 512 vibrations per second and the note C′ 

This may be shown pictorially thus—

	256 vibrations		gives the note	C
Shortened by $\frac{1}{9}$	2304	288	"	D
" $\frac{1}{5}$	1280	320	"	E
" $\frac{1}{4}$	1023	341	"	F
" $\frac{1}{3}$	768	384	"	G
" $\frac{2}{5}$	640	427	"	A
" $\frac{7}{15}$	549	480	"	B
" $\frac{1}{2}$	512	512	"	C′

Here we see how the numbers of the vibrations of each part of

the string differ more and more as they are made more and more unequal, and conversely become nearer and nearer alike as we approach the middle point. Also, that the strings shortened, as we have here described, produce the notes of the ordinary scale. It is familiar to most of us how unpleasantly shrill is the tone produced by the vibration of the short piece of string behind the bridge of a violin. This, we now see, arises from the intense rapidity of the vibrations so produced, following each other at the rate of thousands per second.

I have shown that shortening a string increases the number of vibrations in a given time. From this it would seem that the number of vibrations, or (what is the same) the rapidity of the vibration, is independent of the amount of force applied. What, then, is the difference between the results of two unequal forces applied to the vibration of a string? The number of vibrations will be the same, but the *extent* of *each* vibration and the *intensity* of the sound will be greater, the greater the force—*i.e.*, the more forcibly the string is set in motion, the more forcibly will the air be impelled against the ear. As an illustration of this, the action of an ordinary pendulum may be observed. I set it in motion gently, and it makes a slow vibration; I move it more forcibly, and it moves more rapidly, but through a larger distance. Just so, a string or wire makes the same number of vibrations, whatever be the force applied, but the vibrations are of a larger range, and the motion more rapid. These two, however, compensate each other, so that the only difference between the results of differing forces is in the intensity of the sound.

I have shown also that the division of any wire or string into two equal parts gives two octaves of the original note—that is, each half, when in vibration, gives the same note as the whole string, but an octave higher. But if I divide the string unequally I get two different notes, one above the octave and the other below it, but each a higher note than the original note of the whole string. It is impossible to get from any portion of a string, however divided, a lower note than the note given by the whole.

(22.) **Estimation of Vibrations.**—How can I measure the number of vibrations made by the string of a violin? of a piano? or of a tuning-fork? How can I distinguish from each other vibrations that occur by hundreds, nay thousands, in a second? It is impossible to count the actual vibrations of any vibrating string, but it is not impossible to construct an instrument that shall set air in vibration at a constantly-increasing rate, and having machinery that shall denote the number of the vibrations, just as a gas-meter denotes the quantity of gas that passes through it. This machine, as the number of vibrations increase, will produce a musical note constantly increasing in pitch. But whatever the pitch, the index tells me the number of vibrations required to produce it.

I draw a bow across a violin-string, and desire to know the number of vibrations it makes. To tell this I set my machine at work until it produces the same note; the index tells me the number of vibrations required to produce that note. In the same way I may tell the number of vibrations required to produce any given note.

(23.) **The Syren.**—But what kind of machine can enable me to do this? One called the syren, consisting essentially of two plates of metal of equal sizes, and having a number of holes arranged in a circle. When both plates are placed together, air may be blown through the holes, and will pass through *both* plates. But if the upper plate be made to revolve upon the lower, each hole in the upper plate will pass in succession over *every* hole in the lower plate, and also over every interval between them. If there be ten holes, the air will pass and be cut off ten times in one revolution. If the plate revolve once in a second, there will be ten waves of sound in that time. But if the plate revolve ten times in a second, there would be a hundred waves of sound in a second; if thirty times, three hundred,—and so on. It is easy to make the syren revolve many hundred times in a second, and to have the number recorded.

When the puffs are slow, they are heard as distinct from each other, but as the velocity increases they blend into each other and form a musical sound gradually rising in pitch. The syren is practically two circular plates enclosed in a case, having below an air-chest, and above a recording apparatus. The motion is really given to the revolving plate by the passage of the air through its openings. When any required note is obtained, the plate can be kept revolving at that rate by modifying the supply of air.

Thus, to measure any given note I set the syren in motion, the individual puffs gradually become blended into a musical note, and this rises continuously in pitch. When it reaches the note I desire to measure—that is, when the two sounds are in unison (so that, heard together, they are indistinguishable)—I keep the syren at that rate of movement for one second. The index, which can be set to work and stopped at will, records the number of *revolutions* made in the time, and this, multiplied by the number of *openings*, gives the number of vibrations or sound-waves required.

(24.) **Transmission of Musical Sounds.**—This differs in no respect from the transmission of other sounds, though the effects are often very surprising. Thus a tune may be conveyed from one room to any other: a piano, a violin, a harp, may be played in the kitchen, and the music carried through the parlours and upper rooms to the attics, where it shall be distinctly audible, though inaudible at any other point of its journey. If a long rod of wood or iron be connected with the sounding-board of a piano,

the tune will be conveyed by its vibrations; and if a large disc be placed on the end, so as to present a large vibrating surface, the sound will be at once audible. In the same way a tuning-fork placed at the end of a long rod will sound even at thirty or forty feet distance, if the other end of the rod be in contact with a large vibrating surface. For any one who has not witnessed any illustration of this transference of music it is difficult to realise the accuracy with which every vibration is reproduced.

(25.) **Sounding-Boards.**—A tuning-fork set in vibration in free air is scarcely audible, but if placed on a table, on a basin of water, or in contact with any large vibrating surface, it is at once heard; that is, the vibrations of the fork set in motion the particles of the larger body, and these by their vibration set in motion the air. Every vibration of the small metal fork is reproduced and intensified by the corresponding vibration of the larger surface.

It is in this way that the sounding-boards of musical instruments serve to augment the effect of the vibrating strings, which unassisted in this way would be scarcely audible. All the wires of a pianoforte are attached to a large vibrating board. In a violin the body of the instrument serves this purpose.

A sounding "board" need not necessarily be solid: the surface of a liquid will vibrate as readily and as truly as that of a solid; and a column of water will convey sound as readily, but not so quickly, as a rod of metal or wood. In fact, the differences between liquid, solid, and gaseous conditions of matter are those of degree, not of kind.

(26.) **Vibration of Strings.**—If I divide the string by fastening down any point of it so as to be incapable of motion, then the vibration of one portion will not affect the other; but if I only rest my finger or a penholder on the string, the vibration of one part of it will be communicated to the other, and the whole string will be in vibration. But there will be a very important difference between the vibration of the whole string when free, and when any point in it is pressed with any light weight.

Thus, if I fasten the ends of a string, as on a violin, and draw a bow across it, I set it in vibration as a whole. But if, resting my finger on the string at its middle as one point, I set one half in vibration by means of the bow, I find that the second half vibrates also, and in unison; that is, the force I communicate to one half of the string is passed to the second half, though the middle point vibrates but very little.

Fig. 35 shows the appearance of a string vibrating as a whole; fig. 36, that of the halves vibrating separately. If instead of *stopping* the middle point I rest my finger, a pen, or any other light weight, at one-third from one end, and set the shorter portion, one-third of the whole, in vibration, I find that, as before,

the other part of the string (two-thirds of the whole) is also set in motion by the same force, but with the important difference that it is divided into two portions, each equal to the one-third, so that the whole thread is apparently divided into three spindles, as in fig. 37. So that, generally, by setting into vibration any portion of a string, I divide the whole string into portions of that length, all vibrating alike, and separated by points that vibrate but little. These points are called *nodes*, or *nodal points*. When a string is vibrating in parts, the nodes or points of rest can easily be detected by placing a number of light substances on the string at random. Those at the nodes will remain, all the others will be thrown off by the motion of the string. When the distance between any two points of rest is found, the others can be found by measurement.

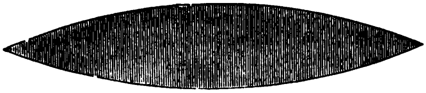


Fig. 35.

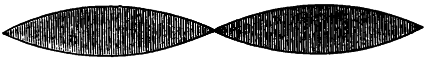


Fig. 36.

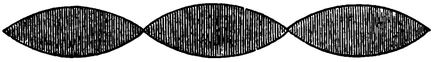


Fig. 37.

(27.) **Vibrations of Plates.**—In describing the vibrations of a wire or string we speak only of the lateral motion, but these are not the only, nor the most regular, of the movements which take place when a body of any kind is set in motion. In fact, just as the terms solid, liquid, and gaseous cease to be, in the study of Physics, terms of rigid demarcation, so the terms length, breadth, and thickness come to have new meanings. The finest wire presents a surface as truly as the broadest plate, and its breadth and thickness are as real as those of a deal board.

We stretch a wire and set it in vibration. Its lateral vibrations are extensive and easily perceptible as compared with other motions amongst its particles, but they are not more real. Thus, if our wire were thick enough, or our senses sufficiently acute, we would note a second motion, at right angles to the lateral vibration, and also note the symmetry between the two motions.

The only reason why a wire is called a wire is that its length is very great as compared to its thickness. If I decrease its length and increase its width, it becomes a plate of metal. A string so shortened and broadened becomes a membrane. It would be difficult to decide where was the exact boundary line between the wire and the plate—between the string and the membrane.

But when I set in vibration a plate of metal these cross vibrations become evident. I get not one, but two sets of vibrations, one at right angles to the other. The *nodal points* become *nodal*

lines—*i. e.*, where in the wire we had *points* of rest, in the plate we have *lines* of rest.

How shall I find these lines? By the same method which enabled me to detect the points. On the wire I placed small pieces of paper; these were thrown off in every case excepting at the points of rest. On the plate I strew fine sand, or any very light and freely-moving powder. The vibrations of the plate move these, but cannot throw them off as the wire threw off the papers. Consequently they gradually accumulate on the lines of rest, or nodal lines, where alone they are at comparative rest. In this way the nodal lines in a plate are very clearly and easily perceptible.

To give a simple illustration: I fix a plate of glass by the middle point in a screw, and holding my finger on one corner *a*, I draw a violin-bow, or some roughened body of that kind, across the middle point of one edge *b*. This sets it in vibration, while my finger prevents the motion of the corner, making it a nodal point; but this point becomes a line crossing the plate from corner to corner. Another nodal line also crosses the plate in the opposite direction. What causes this? The same cause that divides the whole of a wire or string into vibrating portions when one point is held. The two nodal lines cross at right angles, and divide the plate into four equal triangular portions, all vibrating at equal rates, and all set vibrating by the application of force to one of them. Of these four, two are above and two below the nodal lines at any given instant, corresponding exactly to the nodes and vibrating portions of a string, each nodal line being the mean level, having on one side of it a rising and on the other a falling surface.

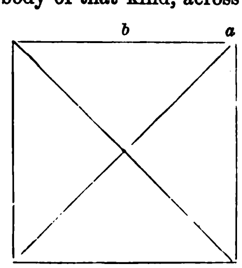


Fig. 38.

If I hold the middle point *a*, and apply the bow to one of the corners *b*, then the nodal lines (still crossing at right angles, but parallel to the sides) divide the plate into four equal rectangular portions, all vibrating as before, two always above and two always below the mean level.

I may hold several points by resting two or more fingers at intervals on one side, and every point so kept at rest will be the end of a nodal line. In this way the most complicated and beautiful figures may be produced by the interference of the lines.

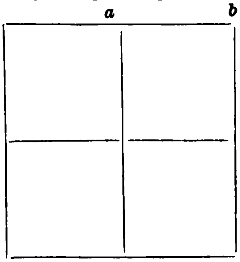


Fig. 39.

Every vibration will produce a musical sound, and the vibrations, pitch, intensity, &c., of these notes follow the same laws as we have seen to obtain in the case of vibrating strings.

Singularly enough, the points of *greatest* agitation are also marked by little groups of the powder, which seem driven to these points by the currents of air generated by the vibrations of the plates. Only the *lightest* of the powder collect here, and if the plate be vibrated in a vacuum, there are no such collections. So it would seem that the movements of the plate drive all the sand to the lines of rest, but that little whirlwinds of air drive back the lightest particles to the centres of motion.

(28.) **Longitudinal Vibrations.**—But it is possible to produce musical tones in still another manner—*i. e.*, by the vibrations of the particles of a rod in the *direction of the length of the rod.* Thus, if I draw some roughened substance, say a piece of leather well resined, *along* a wire, I produce a continuous and *shrill* tone. This is due to the sound-wave generated along the wire. The wire must have a sounding-board—*i. e.*, its end must be fixed to some vibrating surface. The force applied tends to separate the particles of wire, and this is resisted by the cohesion, which confers an elasticity usually very much greater than the force applied. Hence the shrillness of the tone, which varies with the elasticity just as the transverse vibrations do. In fact, the longitudinal vibrations follow almost precisely the same laws as transverse vibrations. The longer the string, the lower—the shorter the string, the higher, the note. In one respect, however, these laws differ: the length-vibrations are more independent of tension. But this may be only an apparent variation; probably the effect due to increased tension is so small, when the vibration is in the same line of action, instead of being, as in transversal vibrations, at right angles to it, that its result is imperceptible.

These longitudinal vibrations afford a means of measuring the velocity of sound-waves in various solids. By noticing the length of any substance required to give a certain note, we obtain the ratio of the velocity of sound in that substance, as compared with that of some other previously ascertained. If 10 feet of one wire give the same note as 15 feet of another, then the velocity of sound in the short wire is to the velocity in the long wire as 2 is to 3 ; for in the one it travels through 10 feet in the same time as in the other it passed through 15 feet. We could not measure the passage of sound through miles of wire, and this test of *pitch* is an easy and an accurate means of measurement.

SUMMARY.

The ear is the **organ of sound**—*i.e.*, by its mechanism we are conscious of the existence of sound.

This mechanism consists of the **auditory nerve,** the **tympanum,** the **Eustachian tube,** the **drum,** the **labyrinth,** a set of very fine **hairs,** and a **lute.**

The **auditory nerve** is the medium of perception : when it is in motion we have **sound.** It is set in motion by the action of the **hairs** and **lute.** These are set in motion by the movements of water with which the **labyrinth** is filled. The **lute** is a wondrous apparatus of some *three thousand* stretched filaments, varying in pitch; these convey to the brain **musical sounds.** The **hairs** are free at one end, and grow between the fibres of the nerve. These convey continuous sounds to the brain.

The **labyrinth** is a cavity, filled with water, behind the **drum,** with which it is connected by a long partition.

The **drum** is another cavity, having within it a group of small bones, set in motion by the movements of the **tympanum,** a membrane closing the outer opening of the ear, and acted upon by the motions of air outside it.

A **sound-wave** acts on the **tympanum,** this on the bone in the **drum,** these on the water in the **labyrinth,** this on the **hairs** and the **lute,** and these on the **auditory nerve.** The motion of this nerve **is sound. Sound** is the perception by us, through our ears, of the existence of *sound-waves* in the substance (usually air) in contact with the *tympanum* of the ear. Sound exists *only* in the motion of the particles of the *auditory nerve.* There is no sound anywhere but in the ear. Page 17.

Anything which acts in this way upon the **tympanum** is a cause of sound. Page 19.

A **sound-wave** must strike on the **tympanum** at least 16 times per second to produce a continuous sound. A **sound-wave** that strikes it more than 38,000 times per second is inaudible. The perception of a sound lasts about $\frac{1}{16}$ of a second. Page 20.

A **sound-wave** is a vibration to and fro. Its *form* depends on the body whose motion causes it. An explosion in the centre of a room would cause a *spherical* wave : the prong of a tuning-fork causes by its vibrations a *radial* wave, proceeding from the fork, and gradually widening in a fan-like manner. Page 20.

The **intensity** of a sound depends upon three things—the

density of the medium, its *elasticity*, and the *distance* the sound has travelled.

The denser the medium, the less the sound.

The greater the elasticity, the greater the sound.

The greater the distance, the less the sound.

If there be two media, A and B—then

$$\text{Intensity in A} : \text{Intensity in B} :: \begin{cases} (\text{Density of B})^2 : (\text{Density of A})^2. \\ (\text{Elasticity of A})^2 : (\text{Elasticity of B})^2. \\ (\text{Distance in B})^2 : (\text{Distance in A})^2. \end{cases}$$

This may be summarised by saying—

The intensity varies *directly* with the square of the elasticity, and *inversely* with the squares of the density and the distance.

The **intensity** of a sound depends upon the density of the air in which it was generated, and not of that in which it is heard.

Page 21.

The amplitude of a sound-wave is the distance that each particle of a sound-conveying medium moves to and fro.

Page 22.

A sound-wave is **reflected** when it falls upon a smooth surface. *The angle of reflection is always equal to the angle of incidence.*

Page 25.

An **echo** is a peculiar phase of reflection, when two points are symmetrically placed with reference to some reflecting surface or surfaces, so that any sound produced at one is heard at the other, not only by direct transmission but also by reflection.

Page 26.

A sound-wave is **refracted** in passing from one medium to another of different density. Page 28.

Sound may be **condensed** by a suitable arrangement of reflecting surfaces or refracting substances. Page 28.

The velocity of sound is the rate at which a sound-wave travels through any medium. The more elastic the medium, the greater is the velocity: the more dense it is, the less is the velocity.

$$\left.\begin{matrix} E : E^{\frac{1}{2}} \\ D^{\frac{1}{2}} : D \end{matrix}\right\} :: V : V'$$

	Per 0° C.	10° C.	20° C.
In Air the velocity of sound is	1.090	1.110	1.130
" Oxygen, "	1.040		
" Hydrogen, "	4.164		
	15° C.	30° C.	60° C.
" Water, "	4.714	5.013	5.657
	20° C.	100° C.	200° C.
" Lead, "	4.030	3.951	
" Gold, "	5.717	5.640	5.691
" Silver, "	8.553	8.658	8.127
" Iron, "	16.822	17.386	15.483
" Wood, Aspen (along fibre),	16.677	5.297	2.987

Page 30.

The **density of the sound-medium** counteracts its elasticity more or less, and tends to decrease the velocity of sound: not because of the greater number of particles to be moved, but because of the greater force of cohesion, which acts in opposition. Page 32.

The **elasticity of the sound-medium** is the force that resists compression. The greater this force, the greater the velocity of sound in that medium. Page 32.

The **temperature of a sound-wave** is increased by compression, and decreased by expansion. The elasticity of the medium (and, consequently, the velocity of a sound-wave) is increased by the compression more than it is decreased by the corresponding expansion, and the result is that the *actual* velocity of sound is greater than was the *calculated* velocity, until the fact was observed and taken into account by Laplace. Page 34.

A musical sound is any sound repeated at *regular intervals*, and more than 40 times per second. Page 41.

The pitch of a musical note depends upon the number of vibrations made in any given time. The greater the number of vibrations, the higher the note. Page 42.

A tuning-fork is a convenient instrument for producing musical notes, since it vibrates regularly and rapidly. It is a bar free to vibrate at both ends, and having two nodal points, which, when the bar is bent, approach nearly to each other.

In considering the **vibrations of strings or wires**, four things have to be taken into account—length, thickness, density, and tension. Any increase of length, thickness, or density decreases the amount of vibration; any increase of tension increases the vibration. In comparing the rate of vibration of two strings, we have the following proportion:—

$$\left.\begin{array}{lcl} \text{Length } a & : & \text{Length } b \\ \text{Diameter } a & : & \text{Diameter } b \\ \sqrt{\text{Density } a} & : & \sqrt{\text{Density } b} \\ \sqrt{\text{Tension } b} & : & \sqrt{\text{Tension } a} \end{array}\right\} :: \text{Vibration } b : \text{Vibration } a.$$

The *diameter and density* may together be replaced by the *weight*: and then we have—

$$\left.\begin{array}{lcl} \text{Length } a & : & \text{Length } b \\ \sqrt{\text{Weight } a} & : & \sqrt{\text{Weight } b} \\ \sqrt{\text{Tension } b} & : & \sqrt{\text{Tension } a} \end{array}\right\} :: \text{Vibration } b : \text{Vibration } a.$$

The syren is an instrument for ascertaining the number of vibrations required to produce any given note. Page 48.

Musical sounds are **transmitted** by liquids or solids, as well as by air. Page 48.

The **vibrations of strings** must be communicated to the particles of larger surfaces, in order to produce audible sounds. Page 49.

A string or wire of any length, when vibrating as a whole, also usually vibrates in halves, &c., in additional vibrations. These

smaller vibrations, depending for their number and extent upon the nature of the sounding-boards to which the strings are attached, make the difference of "tone" by which we can tell one musical instrument from another.

The surface of water may be set in wave-motion in precisely the same manner as a string or wire. Page 49.

The **nodal points of a vibrating string** or wire may be experimentally found as being the points where small pieces of paper, thread, &c., will remain at rest. In the same way the **nodal lines of a vibrating plate** may be found, as being the lines where fine powders strown loosely on the surface finally accumulate.

A **vibrating plate** may be considered as a **vibrating string** widened, so that it vibrates not only in length but also in breadth. Page 50.

The **nodal points or lines** of a vibrating body are determined by the points that are kept at rest.

The points of most violent vibration are marked by little clusters of the lightest powder or sand. These are caused by movements of air occasioned by the vibrations. In a vacuum all the sand moves to the nodal lines. Page 52.

Longitudinal vibrations can be excited in the same way as transverse vibrations, and obey generally the same laws, excepting that they are not so dependent on *density*. Page 52.

HEAT.

(1.) **Introduction.**—If any substance be exposed to the action of heat it is affected in a twofold manner: it gets warm, and increases in size. But the increase of temperature (which we call warmth) is not the same for all substances, neither is the increase of volume. If I place side by side, under equal conditions, a solid, a liquid, and a gas, I find that—

1. The solid rises in temperature more rapidly than the liquid, and the liquid more rapidly than the gas.
2. The solid expands in volume less than the liquid, and the liquid less than the gas.

The heat applied produces two effects: an increase of volume and a rise of temperature. These two may be considered as quite independent effects, for it is quite possible to have one without the other. If a body be prevented from expanding, its temperature will rise the more rapidly.

We may therefore consider that heat performs two distinct operations on any substance to which it is applied, and that the more it has to do one of these the less it can effect the other, and *vice versa*.

(2.) **Solid, Liquid, and Gaseous Conditions interchangeable by means of Heat.**—A solid may be considered as an aggregation of particles of matter held together by attraction. If the sun has power at a distance of more than ninety millions of miles to attract the earth, and if this power of attraction increase as the distance decreases, but in a greater ratio, then we may reasonably suppose that bodies in actual contact have attraction for each other in a much higher degree than might at first be expected. If two plates of glass, both truly level, be placed together, they adhere, not merely by the pressure of the external air, but by the force of cohesion as well. For the same reason, if two heavy pieces of iron have each a face made really a plane surface, and these two surfaces be brought into contact, the two pieces of metal become practically one.

A pound of ice may be converted into a pound of water, and the water into a pound of steam. The difference between the steam and the water, the water and the ice, is the degree of compactness in which the particles are arranged. The steam is quite invisible, because these particles (though just as completely existing and present as in the water or ice) are too distant from each other for the light from them to fall upon the eye in sufficient strength to excite the optic nerve, and so give to the brain the sensation of perception by sight. As much light (probably even more) falls upon each atom as when they are visible as a liquid or a solid; but just as there are sounds that are feeble for our hearing, so there are rays of light too feeble to make any impression on our sense of sight.

In the ice these particles are closely arranged, and occupy sufficient space to reflect light sufficiently to impress the eye with its image. If one particle be moved the whole moves, because of this cohesive attraction. It is probably one of the most accurate definitions of a solid to say, that it is a body of which every particle moves if any one be moved—*i.e.*, that the particles are bound together as a whole.

Between these two states, the *solid* ice (in which the atoms make up as it were a larger atom, and the force of attraction, because of the nearness, overcomes the individual existence of each) and the *gaseous* steam (in which the atoms are so far apart that the attraction is not sufficient to enable one so to influence another, and each atom preserves its individual existence), we have the neutral or common condition of the *liquid* water, in which the two forces are so equally balanced as to give the compactness of a solid with the individual freedom of the atoms as in a gas. These changes, of ice to water, of water to steam, of any solid to a liquid, and of any liquid to a gas, can be effected only by heat. The corresponding changes, from steam to water, from water to ice, can be effected only by the abstraction of heat.

Heat is supposed to be a vibration; therefore the more heat the greater the vibration. If this vibration be prevented—*i.e.*, if a body be compressed so that the vibration of its particles be stopped, partly or entirely, the heat is given off as temperature —*i.e.*, the vibration is communicated to the air, or to any other body in contact.

Thus, to change ice to water, to melt lead, or any other metal, to boil water into steam, or to convert any other liquid into a gas, the application of heat is the only means. This change, with few exceptions, is always accompanied by an increase of volume, rendered necessary by the increase of vibration. The more heat, the more vibration; the more vibration, the more room is required.

To change steam into water, or water into ice, just the reverse process is necessary. Heat must be abstracted—*i.e.*, vibration *must be reduced.* This change is, with few exceptions, always

accompanied by a decrease of bulk. The less vibration, the closer can the atoms approach each other, the less is the force of attraction counteracted.

In this way, by regarding heat as a vibration,—one phase of a force that cannot be destroyed—that, driven from one place, goes to another—that may be divided or accumulated, but cannot be got rid of altogether,—we may regard the gradual change of any body from the solid, through the liquid, to the gaseous form of existence, as the result simply of a continued increase of vibration imparted to its particles.

The expansion of solids when heated is but small—in no known case is it so much as .003 or $\frac{3}{1000}$ increase between 0° and 100° C.; while in liquids, the increase, for the same range of temperature, is much greater, in one case (alcohol) being more than .1 or $\frac{1}{10}$; and in gases it is more than .3 or $\frac{3}{10}$, nearly $\frac{1}{3}$. These variations are the necessary results of what we have just learnt respecting the constitution of solids, liquids, and gases.

(3.) **Effects of Heat upon Gases.**—In a gas the expansion is greatest because the heat has only to overcome the pressure (of the air, or otherwise) which prevents ordinary diffusion. The particles of a gas being quite independent of each other, repel each other (by reason of their vibrations) so much, that any quantity of gas, however small, seems capable of filling any space, however large; so that, to contain any given quantity of gas within known limits, it is necessary to subject it to pressure, as by placing it in vessels, or bladders, &c. When, therefore, we say that a gas expands by the addition of heat, we mean that the pressure which at a certain temperature keeps it within certain limits is, by an increased temperature, forced back so as to allow to the same quantity of gas a greater space. Thus, I fill two bladders partly full of gas, of any kind, so that the pressure of the air upon the outside of the bladders prevents the gas from filling up the entire space. I put one of these flaccid bladders in the receiver of an air-pump, and relieve it of this pressure. The gas instantly swells it out to its full extent, though it contains no more gas than before, but the cessation of the external pressure allows the expansion. I place the other bladder, still under the pressure of the air, before a fire, it also swells out as the other. So long as the one bladder remains free from external pressure, so long the gas will completely fill it, but no more will happen. But if the one exposed to the fire remain so, not only will the gas fill the bladder, but it will eventually burst it, owing to the continued increase of force derived from the increased heat. The gas fills one bladder because there is no pressure upon it, and a gas will, by its nature, occupy whatever space it has access to; but so soon as the bladder is distended the gas is restrained by it, and expands no more. But in the other case the gas distends the bladder despite the pressure of the *air upon it, by virtue* of the additional force commu-

nicated from the fire; and this is continuously increased, the bladder being eventually rent by its force.

Therefore the only work to be done by heat when communicated to a gaseous body is to enable it to overcome any pressure to which it may be subjected. Its temperature must be at the same time kept up, otherwise the vibration would be transformed to heat, by the demand for heat by the lower temperature. So that heat communicated to a gas raises its temperature, thereby enduing it with a higher degree of vibration, that enables it to expand even under pressure.

(4.) **Effects of Heat on Solids.**—But heat, when communicated to a solid, has a much more complex task to perform. A small piece of any solid put into a bladder would not expand when the pressure of the air was removed, as a gas would. Nor even when heated does it expand in any considerable degree, because the atoms are held together by cohesion. Supposing the temperature to be very low, the solid will scarcely expand at all on the application of heat, which will be almost entirely spent in loosening the particles, and communicating to them vibration.

In addition to this, the atoms raised in expansion are raised in opposition to gravitation, since the particles are so near each other that they are not, as in a gas, free from this force.

Thirdly, the air has to be pushed back, unless the experiment be performed in a vacuum; and, lastly, the temperature of the body has to be kept up.

This will explain why a solid expands so little as compared with a gas, since so much of the heat is used in overcoming the force of cohesion.

(5.) **Effects of Heat on Liquids.**—In the case of a liquid, the condition is intermediate between a solid and a gas. The atoms are free to vibrate individually, without the necessity of their being first separated; but they have to be raised, in expanding, against the force of gravitation, and the temperature has to be kept up.

(6.) **General Effects of Heat.**

In a solid, heat has—

1. To overcome cohesion, *i.e., separation;*
2. To impart vibration, *i.e., heat;*
3. To raise the particles against gravitation, *i.e., expansion;*
4. To increase the temperature.

In a liquid, it has only—

1. To impart vibration;
2. To raise the particles against gravitation;
3. To increase the temperature.

In a gas, it has only—

1. To impart vibration;
2. *To increase* the temperature.

That heat has this varied work to do, explains many otherwise puzzling phenomena.

(7.) **Expansion by Heat.**—I fill a long tube a with gas, and close it by a circular plate b, that will move, air-tight, in the tube. The weight compresses the gas, and the plate sinks in the tube, the upper part of which fills with air; so that the gas is pressed down by both the weight of the plate and the weight of the air. I apply heat, and the gas rises in temperature, and also expands; that is, the work done by the heat is twofold. One portion of the heat received by the gas is used in driving the particles of gas further apart, and the remainder in increasing its temperature. The heat used in the expansion is not perceptible, except by the increased volume of the gas, and the consequent rise of the plate in the tube from c to d.

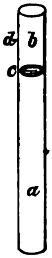


Fig 40.

I now fill the tube as before; and after it has been compressed to c by the plate resting on it, I fasten the plate so that it shall not allow the gas to expand. Applying heat as before, I find that the temperature increases more for the same amount of heat—or, what is the same, any given increase of temperature is attained with less heat than when the gas could expand; that is, the heat that was previously used in lifting the weight of the plate from c to d, and the air above, is now used to increase the temperature, so that the whole of the heat, or nearly so, goes to effect that. I say *nearly so*, because the whole apparatus—tube, cap, &c.—expands slightly (and consequently allows a slight expansion of the gas) as it becomes warmed by the heat.

When the gas is free to expand, part of the heat is translated into motion, and is therefore imperceptible as heat. When the gas cannot expand, no such translation takes place, and the whole of it remains as heat.

This translation of heat into motion is still more perceptible in the case of a liquid or a solid. I put side by side a pound weight each of platinum, of mercury, and of hydrogen—taking platinum as the heaviest solid, hydrogen as the lightest gas, and mercury as the only liquid element—applying the same amount of heat to each. Each will therefore, in the same time, receive the same amount of heat. Will the results be the same? To make the conditions equal, they should all be relieved from the pressure of the air, which may be done by enclosing them in a vacuum.

I apply to each sufficient heat to raise it from 0° to 100° C. The platinum expands but very slightly, the mercury more, and the hydrogen most. The platinum is increased by about a thousandth part of its original length, the mercury by about a hundredth part, while the hydrogen occupies one-third more room than at first. Tables of expansion are given at the end of the book.

(8.) **Increase of Temperature by Heat.**—But this is not the only variation in the effect of the heat communicated. I find that the three substances do not take the same time to rise in temperature from 0° to 100° C. Beginning with them all at 0°, and applying heat in the same quantity to each, I find, nevertheless, that the platinum rises in temperature most rapidly, and the hydrogen most slowly.

It follows from this that the same heat does not always produce the same temperature. If, instead of heating the equal weights of platinum, mercury, and hydrogen from 0° to 100°, and using for each the amount of heat required, I apply to each equal amounts of heat, and note the results, I find that the platinum has risen most in temperature, the mercury nearly as much, but the hydrogen very little in comparison—not more than a hundredth part.

I have hitherto taken *equal weights* of each substance, without reference to their bulk. But these volumes are very unequal. A pound of platinum is but a small piece; a pound of mercury is half as large again as the pound of platinum, but can be contained in a small bottle; while the pound of hydrogen will occupy a very large space indeed—240,000 times as much as the pound of platinum. So that, while the pound-weight of platinum or of mercury can with ease be put in a waistcoat-pocket, a pound-weight of hydrogen requires almost a small room to contain it in its ordinary condition. This will doubtless decrease the surprise at the small effect heat has in raising the temperature.

I now take, not equal weights, but *equal volumes*, of the three elements, platinum, mercury, and hydrogen. If the mercury weigh a pound, the platinum will weigh nearly a pound and a half, and the hydrogen will have no appreciable weight, being not more than one ten-thousandth part of an ounce. I apply, as formerly, equal quantities of heat, and note the rise in temperature. The platinum will show the greatest rise, as before; the mercury nearly as great an increase; and the hydrogen about one-seventh as great, being still less than the other.

(9.) **Sources of Heat.**—Heat is obtained—

1. *From the Sun;*
2. *By Chemical Action;*
3. *By Mechanical Means.*

Heat from the Sun.—This is regular and continuous. As to its source we can only conjecture.

Heat from Chemical Action.—Whenever any substance is burned, heat is evolved. Thus, if we burn coals or candles we obtain heat. In burning a candle a certain amount of heat is caused by the union of the carbon and oxygen to form carbonic anhydride; but only a part of this heat is emitted, some of it

being required to keep the constituents of the gas in the gaseous form. In burning phosphorus we get, on the contrary, more heat evolved than is due to the chemical combination of the phosphorus and oxygen; for the product (phosphoric anhydride) being solid, heat is emitted by the solidification of the oxygen, as well as from the combination of the phosphorus.

Generally, heat is given out whenever chemical combination occurs, and absorbed whenever decomposition takes place. But when one combination is broken up, and another effected by the same means, then heat is absorbed by one power and evolved by the other, the result being an absorption or evolution, according to which of the two is the greater. Thus, if we pour dilute sulphuric acid on zinc, the zinc will decompose some of the water, and combine with the oxygen thus set free, forming zincic oxide, which will again combine with sulphuric acid, to form sulphate of zinc. The bottles, the zinc, the sulphuric acid, and the water, will all be cold, in the ordinary sense of the word; but when the acid is added to the zinc, and the chemical action occurs, the bottle containing the mixture will become very sensibly heated. The zinc decomposes the water, and thus absorbs heat; the zinc then combines with the oxygen, this evolves heat; the combination of the oxide of zinc with sulphuric acid evolves additional heat. The heat felt when the bottle is held in the hand is the heat remaining after the heat absorbed has been taken from that evolved.

Besides this absorption and evolution of heat from chemical changes, there is also the absorption and evolution owing to expansion or compression. Expansion absorbs heat; compression evolves it. We may say that expansion is effected by heat forcing the atoms of the matter expanded farther apart; and that when these are compressed again, the heat previously absorbed is expelled.

Heat from Mechanical Action.—**Friction** and **percussion** are both means of obtaining heat. By rubbing two bits of dry wood briskly together we may, in time, get even a spark; striking a flint and a piece of steel sharply together was the ordinary way of obtaining a light less than forty years since. By the present system—the use of lucifer-matches—we are dependent for the light obtained upon the development of heat by friction and percussion combined. The match is tipped with a chemical compound that bursts into flame if its temperature be raised. By a slight stroke on the wall, which is percussion, and by being rubbed along it, which is friction, the temperature is so raised, and the match is set fire to. Two pieces of ice rubbed together will be melted by the heat generated by the friction. Water has been made to boil, by Professor Tyndall, in his lectures, by means of the heat produced by compelling a brass tube to revolve rapidly in close contact with hard wood.

(10.) **Measurement of Heat.**—In estimating the quantity of heat contained in, or imparted to or by, any substance, we have two difficulties. Firstly, we do not know what it is we desire to measure; secondly, we do not know how to measure it. If we make a metal ball hot, it weighs no more than before; if we make it as cold as possible, it weighs no less. Therefore heat cannot be weighed.

If I put my left hand in cold water and my right in hot, and then suddenly put both together in warm water, I shall feel in the right hand the sensation of cold, and in my left hand the sensation of heat—that is, I cannot feel cold as cold, or heat as heat, but only that one thing is colder or hotter than another. If I put my hand first in cold water and then in warm, I get a sensation of warmth; but if I put my hand first in warm water, then in hot, and then back again in the warm water, this will give me first the sensation of warmth, and secondly that of cold. Therefore I cannot measure the quantity or intensity of heat by my sensation—*i.e.*, I cannot *feel* how much heat any substance has.

But substances, on being heated, usually expand, though sometimes very irregularly. Thus water which half fills a small tube will occupy more than half the space when heated. This, therefore, might be used, with proper arrangements, as a heat-measurer or thermometer. *Thermo* means heat, *meter* means measure; therefore a thermometer is a measure or measurer of heat. But water is only available between small limits: it will not serve to measure temperatures above its boiling-point, when it becomes steam; or below its freezing-point, when it becomes ice. Water not being suitable, we might try air, and should find it very sensitive as a heat-measurer. If a thin glass globe be filled with air, it will be found that the warmth of a hand placed on it is sufficient to cause the air to expand. But this degree of sensitiveness is really too great to be serviceable in practice, since other causes besides changes of temperature—such as pressure of the atmosphere—causes expansion or contraction.

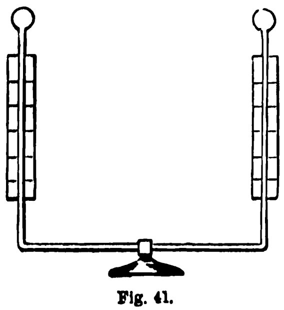


Fig. 41.

Fig. 41 is an air-thermometer, made in a form called a **differential thermometer,** consisting of a tube of glass terminating in a globe at each end. This tube is bent, as shown in the figure, and is partially filled with a coloured liquor, which, by its weight, settles in the lower part of the tube, rising in both arms. The upper parts and the two bulbs are filled with air. If either of these be heated more than the other, the air in that one is expanded and

drives down the liquid. But this, when so driven down in one arm, must rise in the other, and this it can only do by compressing the air in the cooler bulb. So that the amount of movement in the liquid column is determined by the force of expansion in one bulb of air over the resistance to compression of the air in the other bulb. No change of temperature in the room has any effect, because it affects both bulbs alike. If I apply the same amount of heat to each bulb, I confer on each an expansive force, and these two forces counteract each other—the liquid, being equally pressed at both ends, remains stationary. Consequently the movement of the liquid, which is marked on the registers at the side, testifies, not to the absolute presence of heat, but to the presence of more on one side than on the other, to the *difference* of the amounts present; hence its name of *differential thermometer*. Examples of its use are given in the discussion of transference of heat.

Generally speaking, it may be said that solids expand and contract too little, and gases too much, to be available as thermometers. Turning our attention to liquids, it will be found that **Mercury** (which is the only elementary substance that remains liquid at all ordinary temperatures) is the most convenient. An ordinarily good thermometer should measure temperatures varying from several degrees below the freezing-point of water to several degrees above the boiling-point. By means of mercury (which freezes only at a temperature much below that of ice, and volatilises only at a temperature very much above that of boiling water) this can be effected.

(11.) **The Thermometer.**—A fine column of mercury is enclosed in a glass tube of small bore, and filling only a portion of it. The remainder of the tube is a vacuum, the air having been carefully excluded. Heat causes the mercury to expand, and so fills more space in the tube; cold causes its contraction. The tube containing the mercury is fixed on a small wooden frame, the sides of which serve as the register. The tube so partly filled with mercury is put in ice, which causes the mercury to contract. The point to which it descends is noticed, and a mark put on the frame at the side. Whenever the thermometer is exposed to the same degree of cold it will contract to the same extent. When, therefore, we see that the mercury stands at that point, known by the mark against it, we know that the temperature is that of freezing water. The same tube is then placed in the steam of boiling water, which expands the mercury. The point to which it expands is now marked, and becomes the boiling-point of the thermometer. These two points, the freezing and boiling of water, are taken because they are always the same, and because between these two the mercury expands and contracts several inches, thus enabling intermediate temperatures to be marked with clearness.

These two points, the freezing and the boiling points, are thus the foundations of the thermometric scale—the standards with which all other temperatures are compared. Thus we speak of one as being so much below the freezing-point, of another as so much above it, of a third as so much above or below the boiling-point.

Then comes in an important point for consideration. How shall these comparisons be expressed? Practically there are three methods in use, and the following diagram will show the three, with their differences.

These all agree in the position of the freezing and boiling points, as being those of the freezing and boiling of water. They differ in each having the space between these points, and above and below them, divided in a special manner. In the Centigrade thermometer the space between the two fixed points is divided into 100 equal parts; in the Reaumur the same space is divided into 80, and in the Fahrenheit into 180, equal divisions. In all three these divisions are carried above the boiling-point and below the freezing-point, and marked in continuation. In the Centigrade and Reaumur the degrees are marked upwards and downwards from the freezing-point; in the Fahrenheit they are marked upwards and downwards from a point 32° below the freezing-point, so that water is said to freeze at 32° Fahr. But it must be carefully remembered that a thermometer can only express what is called *temperature*—it cannot measure or express *heat*. Thus a thermometer placed in freezing water would mark 0° C. or 32° F., whether the quantity of water were large or small, although obviously there must be more heat in a large than in a small quantity.

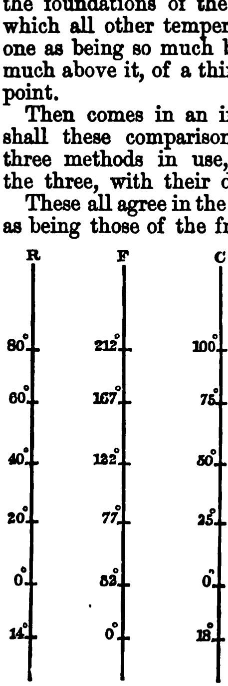


Fig. 42.

Again, if placed in steam, a thermometer would mark 100° C. or 212° F., whether the steam were issuing from a tea-kettle or a locomotive boiler. Also, whatever heat was forced into steam would not, however great the quantity, be expressed by the thermometer, which would not rise above 212° F. or 100° C. Naturally this must be so, for the thermometer is not a thinking being, but a physical agent. It acts only by the expansion of the mercury, which can only be affected by the heat *given out*, and not by that *contained*, by any given substance.

This heat *given out* is the *temperature* of a body, the heat *contained* is the *heat* of it. The temperature can be expressed by the thermometer; we have no means of measuring the heat contained in a body except approximately and by indirect methods.

(12.) **The Pyrometer.**—When the temperature is above what can be measured accurately by the thermometer, another instrument, called a pyrometer, is used, the principle of which is really the same.

The expansion of a liquid is a better test of temperature than that of a solid, which is very small, or of a gas, which is invisible. But when the temperature is so great that it would vaporise any liquid, we can only measure it by the expansion of a solid. Thus in "Daniell's Pyrometer" a piece of platinum is enclosed in a tube of plumbago, and exposed to the temperature to be measured. The expansion of the platinum is measured on a scale, which is marked, as in the case of the thermometer, according to the expansion effected by temperatures that are already known.

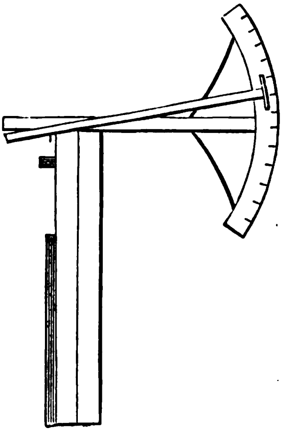


Fig. 43.

Another pyrometer is a metal ball and a vessel of cold water. This is used for measuring the heat of furnaces. A steel or platinum ball is placed in the furnace at the end of a long rod. When it has acquired the same heat as the furnace, it is made to roll down a tube into a vessel having a known quantity of cold water at a known temperature. The heated ball raises this temperature, and by the amount of this increase expresses the temperature of the furnace. It is easy, by measuring the rise of temperature in the water (the relative volumes of the water and ball being known), to estimate the heat of the ball, and therefore of the furnace.

A solid thermometer is also made by fastening together three thin strips of metal, one gold, one silver, the third platinum. These expand unequally when heated; silver increasing in length 1 in 524, gold 1 in 682, platinum 1 in 1131, for 100° C. Therefore if the temperature of a compound bar formed of these three metals be increased, it will bend on one side because of the greater expansion of the silver and the less expansion of the platinum as compared with that of the gold. On the contrary, if the temperature be diminished, the bar will bend the reverse way, because of the greater contraction of the silver and the less contraction of the platinum as compared with that of the gold. By observing and registering the amounts of curvature for given temperatures, such a compound metal bar may be used as a thermometer. It is more convenient to have the bar made in a curl, as a watch-spring. Such a spiral will be curled still more by heat, and partially uncurled by cold, or *vice versa.*

Another method of measuring high temperatures has been recently tried. This is by decomposing marble by heat, and measuring the tension of the carbonic acid set free.

(13.) **The Thermo-pile.**—Expansion is not the only property of heat, and though this property, as used in the thermometer and pyrometer, is useful to show variations in temperature, it is necessary that we should have a much more refined and delicate test of change than either of these instruments. For this we have to turn to some other property of heat, and we find that it has the power of developing, or being developed, into an electric current. Thus, if I make a metallic hoop, one half zinc and the other half copper, and place a source of heat, such as a candle, at one of the points where the metals are joined, I find that an electric current is excited in the wire. The explanation of this result seems to be that the current of heat passing by the copper travels faster than that passing by the zinc, and whenever two unequal currents of heat come into contact, the result is an electric current. Why it should be so I am not able to tell you.

By using this property of heat, I am able to construct a very delicate thermometer, called a **thermo-pile.** I require two metals of different conducting powers for heat, and some way of showing the presence and intensity of the current generated. The two metals usually employed are bismuth and antimony, because they differ so much in their conductivity for heat; and instead of being arranged in a hoop, they are placed in straight pieces, side by side, one of each metal alternately. Fig. 44 represents the end view of a *pile* of bars of antimony and bismuth, separated by non-conductors, and joined only at the ends. By using a number of bars, the effect is greatly increased. Fig. 45 shows a single row of bars.

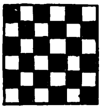


Fig. 44.

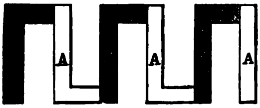


Fig. 45.

But how shall I make the existence and amount of the current appreciable? A feeble current of electricity passing through a copper wire does not show any signs of its presence. I have explained, in a later part of the book, how this is done, and for the present will assume, without explanation, that a current of electricity will deflect the needle of a galvanometer, if it be allowed to pass through it. By connecting a galvanometer to the ends of the *thermo-pile*, by means of a wire, I may detect the presence of a current, and the amount of deflection will also show the strength of the current. The thermo-pile may also be a measure of diminution of temperature; for if any cold body, say ice, be placed near the face, a current of electricity will be excited, as usual, but passing in the opposite direction.

The most serviceable metals for this purpose are bismuth and antimony; but bismuth, nickel, lead, tin, copper, platinum, silver, zinc, iron, and antimony, may all be used. If any two of these be taken, and heat be applied, the current will pass across the heated point from the first to the last mentioned in the list.

(14.) **Nature of Heat.**—In most books it has been the custom to speak of heat as an entity, as something requring space and exerting force, but so delicate as to be absolutely invisible and without weight. The various effects of heat are considered as being the results of the movements and actions of this substance. Thus expansion is spoken of as being caused by the heat being forced into the interstices of any body, however dense, when it is heated. Contraction or compression is said to develop heat, because, by the particles of the compressed body being forced more closely together, there is less room for the heat to occupy. If I soak a sponge in water, it swells: if I compress the sponge, I expel the water. So, only in a very much less degree, it is supposed that heat increases a body by filling its interior spaces, and that this contained heat can be expelled by compression. In radiation it has been said that inconceivably small particles of this "heat" are emitted on all sides in straight lines; while "conduction" is the passage through any body of these small particles.

But another theory, called the "dynamical theory of heat," regards the phenomena of "heat" in a different manner. Heat is no longer a cause, but simply an effect; we can no longer speak of forcing heat into a substance, or out of it, but of it as having its particles set into vibration so as to communicate to us the sensation of warmth.

I take a small lump of iron and suspend it over a spirit-lamp. In ordinary language, it gets warm. According to one theory, I have forced heat into it, have filled its pores with heat; according to the other, the particles of the iron that are nearest to the lamp are set in vibration by its heat, and these vibrations communicate a similar motion to the adjoining particles, and these to the next, and so on, until the whole of the iron is in motion, and this motion is heat—that is, a body so vibrating possesses all the properties of a "heated" body.

I place a small tube partly full of water over a spirit-lamp. The water at the bottom is heated, and being thus expanded, rises to the top, carrying its heat with it. The next layer, falling to the bottom of the tube, is in turn heated, and also rises. In this way the whole of the water is heated. The only difference between this and the heating of the lump of iron is, that the heat of each particle is *carried* away, instead of making its way from particle to particle. In thus heating the water, I have, by one theory, forced heat into the interstices of it; by the other, I have set each *particle of the water* in vibration—the particles so vibrat-

ing being driven away from the source of heat, and continuing to vibrate by virtue of the impulse originally imparted.

(15.) **Similarity of Light and Heat.**—Heat is in many respects governed by similar laws to those of light and sound. Heat and Light both radiate from any source in straight lines; they are each reflected from smooth surfaces; each has the property of passing through many substances. But they differ in one very important point. If a lighted candle and a jug of hot water be placed on a table together, we have light and heat side by side. The light can be at will extinguished in an instant, but the heat cannot be so summarily got rid of. The room is at once darkened if the candle be extinguished, and the light absolutely ceases; but the heat cannot be so annihilated—it must be *removed.* If left on the table, the water will gradually cool, because the heat will pass away to the air, and, being diffused over a larger surface, be imperceptible to our senses. But it is removed, not destroyed; and this constitutes one remarkable distinction between light and heat — that whereas one is an effect, and can be ended at will, the other seems to possess more the properties of an entity, or actual being, and cannot be done away with. But the difference is more in our powers of perception than in the vibrations themselves. The smallest light is perceptible if it fall on the eye, but we do not so readily feel heat. Moreover, it is probable that light is but extreme heat.

(16.) **Transference of Heat.** — The gradual heating of a lump of iron by the passage of heat along its particles, or by the continual communication of vibration from particle to particle, is an example of "**conduction**" **of heat.** The gradual heating of water, by each particle carrying away its own heat—*i.e.*, by each particle receiving its vibrating action direct from the source of heat, and not by conduction—is an example of "**convection**" **of heat.**

Solids are gradually heated by conduction, liquids and gases by convection.

I suspend a heated ball of copper in a room, and I feel heat to be given off from it on all sides. According to one theory, heat, as an imponderable invisible fluid, is emitted from every point of the heated body; according to the other theory, the ball being hot, is in a state of vibration, and communicates this vibration to the particles of gas or ether which is supposed to fill all space, and the vibrations of the ether being communicated to surrounding objects, set their particles also in vibration—*i.e.*, heat them. In this example heat is said to be **radiated.**

If I place near this ball a tin plate, one half brightly polished, and the other half coated with a layer of lamp-black, it will receive heat from the copper ball, but the part coated with the lamp-*black will* absorb or retain much more of the heat than the

polished portion. It will be found that the heat falling on the bright part is mostly reflected, while that falling on the black part is retained. This **absorption** of heat is the reverse of **radiation.**

The two terms, **conduction and convection,** describe the gradual reception of heat by a body in communication with the source of heat. **Radiation** and **absorption** represent the giving off and reception of heat across an interval of space. Thus, if I place a metal on the fire it receives heat by conduction, but if I suspend the ball before the fire at some little distance, it is warmed by absorption of the heat radiated by the fire across the intervening space. A kettle of water on the fire is warmed by convection.

If I hold a cold piece of metal near a heated piece it will receive some heat from it. The quantity of heat so *radiated* and *absorbed* will increase as I bring the two bodies closer together, and when I decrease the distance until they are in actual contact, the radiation and absorption will become *conduction.*

Conduction, } depend upon the *nature* of the substance heated.
Convection, }

Radiation, } depend upon the *surface* of the substance heated.
Absorption, }

But it must be considered radiation is not a *method* of transfer, but the *fact.* It means that heat, force, energy, vibration, whatever we agree to call it, is given off on all sides by a heated body. To show more clearly what I mean, suppose a heated ball of iron placed on the apex of a pyramid of metal, and below a vessel of water, heat would be *radiated* in all directions, but the passage upward through the vessel A would be by *convection,* downward through B by *conduction,* across the air in C and D by radiation, to use the ordinary term, but really by both *conduction* and *convection.*

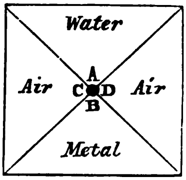


Fig. 46.

If two iron balls be heated to the same degree, and placed side by side — one on a metal stand, and the other on a thick woollen mat—it will be found that one will cool much more rapidly than the other. The one on the metal stand will have its heat carried away by the metal, which is a good conductor; while in the other ball but little of the heat will be carried off by the wool, which is but a bad conductor.

If there were two cisterns equally full of water, one with an open pipe to carry off the water, but the other with a pipe closed by a porous plug, through which the water could percolate but slowly, then we should have the parallel to the two balls full of heat; one supplied with metal conductors to carry off its heat—the other only able to give out but a small amount, with difficulty, through the woollen mat.

Both balls will also gradually cool by radiation of their heat

into the air, and this at equal rates if the balls be of equal size. But if they be covered, one with a bright metal cover not in connection with the metal stand, and the other with a rough, porous, earthenware one, then the bright metal cover will allow of but little radiation, while the rough porous cover will permit the heat to pass off freely. The point to be noticed here is that the metal stand carries off the heat, while the metal cover retains it. Why is this? The metal stand allows the heat to pass readily through it to the floor, and to become thus diffused throughout the room generally. But the metal cover, though a good conductor, is not in communication with anything but the air. Heat, therefore, can only escape from it by radiation; and a brightly-polished surface being unfavourable to this, the heat escapes but slowly.

If two kettles of water be placed near a fire, one above it and the other below, the water in the one above the fire will boil much sooner than the one below it. In this case the heat will be communicated in a manner different from either conduction, as in the case of metals, or radiation, as in the escape of heat into the air. The water at the bottom of the upper kettle will be heated by the fire, and, being thereby expanded in size, will become lighter than the cold water above it, and rise to the top of the kettle. In this way each layer of water will become heated and rise in turn, until at last the whole will boil. But in the case of the kettle below the fire, the upper layer of the water will be heated, and will remain at the top, so that the heat can only get down to the cold water beneath by the process of conduction, as in the case of a solid; excepting that, the particles of the water being less compact than in a solid, the process will be even more slow.

These facts will illustrate the transference of heat by the three processes of radiation, conduction, and convection. Radiation is the projection of heat from any substance of which the temperature is higher than surrounding objects. Conduction is the passage along any substance (such as a metal) that allows heat to pass through it. Convection is when each particle of water as it becomes heated moves farther from the source of heat, carrying its heat with it. This last process is only possible in the case of a liquid or gas. Also notice that conduction and convection are the *methods* of radiation—the two ways in which heat can radiate or pass off from a body.

(17.) **Capacity for Heat**—*i.e.*, *Specific Heat.*—If ice be put in warm water it will gradually melt; but though the water will lose in temperature, the melting ice will not gain. It will remain at 0°, both ice and water, until the whole of it becomes water; that is, the heat abstracted from the water will be used in separating the particles of ice, and in imparting vibration to them. It will also try to raise their temperature; but the ice that is still unmelted will immediately abstract this free heat, as it may be called, and *apply it to itself*; so that the whole heat will, so long as any ice

remains, be used in *work*, and will therefore be imperceptible as heat—or, to use the now almost obsolete term, will be *latent heat.*

Again, if water be boiled, the temperature of the steam will not rise above 100° C., because all the heat above that is abstracted from it by the remaining water.

If water at 80° and mercury at 20° be mixed in equal weights, the temperature of the mixture will not be 50°, as might at first be expected, but 78°.

If water at 80° and mercury at 0° be mixed in equal weights, the water will sink about 3° and the mercury will rise 77°, the resulting temperature of the mixture being about 77°.

If water at 0° and mercury at 100° be mixed in equal weights, the result will not be as before; the water will rise about 3°, and the mercury sink about 97°, the resulting temperature being only a little above 3°.

If water, mercury, and alcohol be exposed to heat in equal weights, it is found that the mercury rises 30° and the alcohol nearly 2°, while the water rises 1°.

If zinc, tin, and lead be similarly heated, the lead will rise 3° and the tin nearly 2°, while the zinc rises 1°.

If oxygen, hydrogen, and steam be heated in equal weights, and under similar conditions, the oxygen will rise 15°, the steam about 8°, while the hydrogen rises 1°.

So that not only does the same quantity of heat produce different effects upon solids, liquids, and gases, but has *different* effects upon *different* solids, liquids, or gases. Of all bodies, hydrogen seems the least affected by heat—*i.e.*, requires most heat to produce any given rise in temperature. Next comes water, which has a greater capacity for heat—*i.e.*, will receive more with less result—than any other known solid or liquid, and greater than any gas, hydrogen alone excepted.

Next is lithium, which has a capacity for heat nearly equalling that of water.

Hydrogen is the lightest of all known substances, and has the greatest capacity for heat—that is, it is the least affected by it. Lithium is the lightest known metal, and of all solids has the greatest capacity for heat. Lead, mercury, platinum, bismuth, are all heavy bodies, and all have but little capacity for heat—that is, they are all readily affected by it.

So that, speaking roughly, we may say that the heavier or denser a body is—that is, the more matter it contains in a given volume—the more rapid and extensive is the action of heat upon it; and the lighter any body may be—*i.e.*, the less matter it has in any given space—the less readily does heat affect it, probably because of the greater distance between the atoms: for it must be borne in mind that the laws of which science teaches us the nature know no distinction between large and small; to them nothing is too vast, *nothing too minute.* The distance between two ad-

jacent atoms of a gas is as real a distance, and affects the power of heat just as truly, as that of the sun from the earth.

We say the specific heat of water is 1—*i. e.*, we take as unity that amount of heat which will raise water to any given temperature, say from 0° to 1° C. I raise 1 lb. of water from 0° to 1°, and measure accurately how much gas, or candle, or whatever source of heat I use, has been consumed. This becomes a standard of heat. I apply the same amount of heat to 1 lb. of mercury, and find I have raised it 30°; or I raise 1 lb. of mercury from 0° to 1°, and find I have only used $\frac{1}{30}$ of the fuel the 1 lb. of water required; or, lastly, I raise 30 lb. of mercury from 0° to 1°, and find that I have used only as much fuel as 1 lb. of water required. From any one, or from all, of these I deduce the fact that water requires 30 times as much heat as mercury to raise it to the same temperature.

To express this, I say that if the heat required by water be 1, then that required by mercury is $\frac{1}{30}$ of 1, or .033; or if the heat required by mercury be 1, then that required by water is 30. The former is the method usually adopted. In the same way we express the *specific heat*, or *capacity for heat*, of any other body. The capacity of water being taken as 1, and being also greater than that of any other substance except hydrogen, the specific heat of any other substance will be less than 1—*i.e.*, will be a decimal.

(18.) **Methods of Estimating Specific Heat.**—In this as in all other experiments we deduce what we seek from what we already know. Thus I put 1 lb. of lead at 30° in 1 lb. of water at 0°, and I find that the lead cools very much more than the water warms. Finally, they have the same temperature, about 1°. From this I deduce that the same amount of heat that raised the lead from 1° to 30°, and which has been transferred to the water, will only raise the water from 0° to 1°; and that, therefore, the specific heat of lead is about $\frac{1}{30}$ that of water—*i.e.*, .0314 really. In the same way I find the ratio of the heat required for any other substance as compared with that required to produce the same effect on water.

A second method is to place any heated body beside the same weight of water raised to the same temperature, and to notice the respective times of cooling to the same degree, or (what is the same) the degree of cooling that each has in any given time. Thus I notice the time that 1 lb. of water takes to cool from 1° to 0°, and also the time that 1 lb. of lead or tin, or any other substance, takes for the same. If one be mercury, and cool 30°, while water cools 1°, then we deduce that the same amount of heat is given off by each, and that the heat required to raise 30° is equal to that required to raise water 1°, as before.

A third method is to notice how much ice can be cooled by any given weight of a body in cooling from any given temperature to

0° C. This is done by enclosing the substance in a vessel otherwise filled with ice, and having an opening at the side. The heated body melts the ice, and the amount of water poured off is weighed. Thus 1 lb. of water in cooling from 80° to 40° will melt more ice than 1 lb. of mercury in cooling the same degree. The one quantity would be about 30 times the other, from which again we deduce that the specific of mercury is $\frac{1}{30}$ that of water.

It might be asked, Why need there be three methods? Why does not one suffice? To which it may be replied that not even all the three suffice to give perfect results. The first—that of mixture—has the weak point, that heat is lost in warming the vessel, and by radiation from its external surface; the second—that of melting ice—which was devised to prevent this loss of heat, fails in that the water formed by the melting of the ice does not all run off, some remaining amongst the ice; the third—that of cooling—fails in that the two cooling bodies have not equal surfaces, and therefore the radiation is not on equal terms. To counteract this, equal volumes, not weights, are taken, and the results calculated accordingly.

(19.) **Causes affecting Specific Heat.**—As might be expected, the same substance has not always the same specific heat; and it then becomes necessary to ask, What are the circumstances that alter the capacity of a body for heat? and to what extent do these affect it?

We say one body has a greater capacity for heat than another when it requires more heat to show the same *temperature.* We have seen (p. 60) that heat has more to do in a solid than in a liquid body; therefore, may we not reasonably expect that if we expose the same body both as a solid and as a liquid to any constant source of heat, more of it will be absorbed by the solid than by the liquid? If we put ice and water before a fire, the ice will rise nearly 2° for every 1° that the water rises. Lead also, if placed both as a solid and as a liquid, will rise 4° as a solid for every 3° as a liquid. And by further experiment, we may find that any substance in its solid form rises in temperature more rapidly than when in the liquid state. This is precisely the reverse of what we looked for. We expected a solid to have the greater capacity for heat, and we find it to have the less.

This is one more example of the necessity of distinguishing between *heat* and *temperature.* Heat is the force within the body; temperature is the portion of that force which is capable of affecting any other body. Heat is the amount of force stored up, as it were, in the whole volume of the body, and increases with the volume; temperature is the amount of force which is upon the surface, and increases with the number of atoms in the surface. If a number of atoms be vibrating with a certain force, their combined force will be more effective if the atoms be close together than if they be separated by considerable intervals. So that the

atoms of a liquid must have a greater vibration in each atom than the atoms of a solid, to produce any given effect. Hence more heat must be supplied to a liquid than to the same substance when solid, for the same rise in temperature; and this because of the greater distance between the atoms in the liquid.

Following out this reasoning, we should expect to find that a solid at a low temperature had a less specific heat than the same substance at a higher temperature; and this we find to be true, not only of solids, but also of liquids. To state the law broadly, we may say that of any substance, solid or liquid, the specific heat—*i.e.*, capacity for heat—rises with the temperature, being greatest for the highest, and least for the lowest. Thus iron below 100° C. has a capacity for heat of .1098, but above 100° it has one of .1218. So mercury rises from .033 to .035, and copper from .095 to .101. Platinum does not vary in this way; but this is probably because of its high melting-point, for this has a great influence — showing that it is the loosening and separation of the atoms that affects the capacity for heat in the way I have mentioned.

In liquids the same holds true. Water below 40° has a specific heat of 1.0013; below 80°, of 1.0035. Bromine below 13° is .105; and above 13° it is .112.

Following out this reasoning, that the specific heat of any substance when liquid is greater than when solid, and that in either it is greater at a higher than at a lower temperature, we should expect to find the specific heat highest of all when the substance was in the gaseous form. Appealing to experiment we find, — ice, .504; water, 1.000; steam, .480. This is the reverse of what we expected. So far from having a specific capacity higher than the liquid, the gas has one less than the solid. Here again our reasoning seems to be at fault, but only because we have not carried it far enough, and taken into account all the circumstances.

In a gas, all that heat has to do is to expand it and raise the temperature. There is no separation of atoms to be effected, therefore a greater portion of the heat is free to raise the temperature in a gas than in either a solid or a liquid, and therefore less heat is required to produce any given effect—*i.e.*, its capacity for heat is less.

Lastly, if we take equal volumes of two gases, one more dense than the other, which will have the greater capacity for heat?—*i.e.*, which will require the greater amount to produce any given effect? Arguing from our previous experiments, we would say that the more dense gas would require the more heat, by reason of its greater compactness, which would counteract a part of the heat applied. And in this we should argue rightly. The denser gas has the greater capacity for heat.

(20.) Atomic Heat.

	Specific Gravity.	Specific Heat.	Atomic Weight.	Atomic Weight × Specific Heat.
SOLIDS.				
Lithium, . .	0.593	0.9408	7	6.5856
Sodium, . .	0.972	0.2934	23	6.7482
Zinc, . . .	6.862	0.0955	65	6.2075
Tin, . . .	7.285	0.0562	118	6.6316
Copper, . .	8.788	0.0951	63.5	6.0388
Lead, . . .	11.445	0.0314	207	6.4998
Gold, . . .	19.358	0.0324	196	6.3504
LIQUIDS.				
Alcohol, . .	0.715	0.6600	20	13.2060
Water, . . .	1.000	1.0000	18	18.0000
Mercury, . .	13.596	0.0332	200	6.6400
GASES.				
Hydrogen, .	0.069	3.4090	1	3.4090
Nitrogen, . .	0.972	0.2438	14	3.4132
Oxygen, . .	1.106	0.2175	16	3.4800

It will be noticed that the specific heat of any solid multiplied by its atomic weight gives always very nearly the same result. Thus the atomic weight of lithium is 7, of copper 63.5; so that if we take an ounce of each, then whatever number of atoms of lithium we have, the ounce of copper would contain but one-ninth as many.

Thus again, if we take a small quantity of lead, and, having weighed it, take also equal weights of gold, copper, tin, zinc, sodium, and lithium, then for every atom of lead, we should have, of gold rather more than 1, of tin nearly 2, of zinc and copper about 3 each, of sodium 9, and of lithium nearly 30 atoms—*i. e.*, the heavier each atom, the less, necessarily, is the number of atoms required to make up any given absolute weight.

(21.) **Relation of Specific to Atomic Heat.**—But the specific heat is estimated for equal absolute weights, without reference to the number of atoms required to make up that weight, and if we divide the specific heats by the numbers of atoms so present in equal weights of various substances, we shall have, as quotients, the specific heats of atoms of each substance.

	Atomic Weight.	Number of atoms present in equal weights, 10 atoms of lead being 1.	Specific Heats of equal weights, water being 1.	Specific Heat of one atom of each.
Lithium, .	7	295.7	0.9408	.00311
Sodium, .	23	90	0.2934	.00326
Copper, . .	63.5	32.4	0.0951	.00296
Zinc, . . .	65	31.8	0.0955	.00300
Tin, . . .	118	17.5	0.0562	.00321
Gold, . . .	196	10.5	0.0324	.00308
Lead, . . .	207	10	0.0314	.00314

The last column shows that (allowing for the inevitable inaccuracies attendant upon mathematical calculations of this kind) the specific heat of an atom of any substance is most probably the same, and that the difference in the specific heats of different bodies arises from the varying numbers of atoms present.

This may be proved also by multiplying the atomic weight of a body by its specific heat (as in the last column of the table on preceding page), the result in all cases being nearly the same.

(22.) **Exchange of Heat.**—If any substance be heated, it gives off heat in all directions. It also receives heat from any other body near it. In this way all bodies tend towards equability of temperature, just as several connected vessels of water have the same level. When I put a lump of platinum, a bottle full of mercury, or of hydrogen, near any source of heat, as a fire, a lighted candle, or a spirit-lamp, the total amount of heat present in the two bodies is divided equitably between them as rapidly as possible; that is, the platinum, mercury, or hydrogen will become warmed from contact with the fire or lamp. This is the primary effect, the expansion being the secondary. If the expansion be prevented, the whole of the heat goes to producing the primary effect of heating, and the temperature rises more rapidly than when accompanied by the corresponding expansion.

Taking the "dynamical theory" of heat as the true one, the particles of a body are only absolutely at rest when at zero—*i. e.*, when the body contains no heat. This is, however, only stating the same fact in other words. The theory supposes that the result of heating a body is to communicate motion (*i. e.*, vibration) to its particles. If these particles are close together, and attracting each other with the force of cohesion, as is the case in a solid, this vibration will tend to separate the particles; just as if, in a crowd of men, each individual were to endeavour to swing his arms to and fro. This would be the more difficult the closer the

crowd, but would tend to separate its constituents, and would do so to some extent, unless entirely prevented by the impossibility of more room being occupied.

If men be forced into a room until the room is quite full, and each has his arms pressed closely to his side, no amount of exertion will enable him to swing his arms to and fro, and his efforts to do so will only tend to make him hot. The case of these men is exactly parallel to that of particles of a solid body that is being heated, and unable to expand. The body is unable to receive the heat, and the whole of it becomes temperature—*i. e.*, affects other bodies near it; but if the body can expand, a portion of the heat is so used, the particles are set in vibration, push each farther away, and the heat so utilised really ceases to be heat, and does not affect the temperature of the body. That is, the same heat cannot affect two bodies at the same time—cannot cause the expansion of one, and at the same time be given off as temperature to another.

If I put a heated ball in cold water the ball cools and the water is heated, until both have the same temperature. Not until each has the same *amount of heat*—because this depends on the quantity and specific heat of each—but until both are in the same state of vibration; *i. e.*, until the whole quantity of heat present in the two is diffused over them both, not in equal quantities, but in such quantities as will, whatever be their bulks or specific heats, keep both in the same state of vibration, so that they may be considered as one body so far as the heat is concerned.

This is true of any two bodies at different heats. When brought sufficiently near for the radiated heat from one to have an appreciable influence upon the other, each continues to give off heat, the temperature of one rising, and of the other falling, until both have the same. According to some theories, the transference of heat still continues even after this, but in equal, and therefore compensating, quantities.

This transference of heat from one body to another may happen in either of two ways—by *conduction*, or by *convection*. If two balls of iron be heated to different temperatures and suspended near each other, the heat will pass from one to the other through the air (or through a vacuum, if there be one), the heat being given off on all sides by each. If they be connected by a wire, this exchange will take place more rapidly, and equality will be sooner attained. If the hotter ball be placed below the other, and they be connected by a glass tube nearly filled with water, the heat will rise from the lower to the upper through the water in a much greater degree than it will pass from the upper to the lower.

In all three cases, through the air, the wire, or the water, heat will pass, but in different ways, and with different results in the same time.

(23.) **Radiation of Heat.**—If there be a vacuum between the two balls, they can only exchange or equalise their heats by the method of radiation—*i.e.*, the heat is given off in straight lines, of which some impinge upon the other ball. But if heat be a vibration, how can these vibrations pass through a vacuum? This is a very important question, and the answer to it is not so clear as might be wished.

If a bell be hung in a vacuum the sound of its ringing will be inaudible, in fact it will not *ring*, because there is no air which can vibrate, and so convey the vibration called sound from the clapper to the ear: but the bell is distinctly visible if the vessel containing it be transparent; so that light can evidently pass through a vacuum, or a substance too delicate to be the medium of sound.

Then comes another question: Is there such a thing as an absolute vacuum? We know it to be very difficult, even with accurately-constructed machinery, to obtain what is ordinarily called a vacuum—*i.e.*, the absence of any medium sufficiently dense to convey sound, to have weight, or to be appreciable by our senses of hearing and feeling. But when we have done this, may there not still remain some more subtle medium which, though it does not convey sounds, and seems to have no weight, may really exist, and be the means of conveying the finer vibrations of light and heat? That there is such a medium (usually called an *ether*) is the assumption made to account for the passage of light and heat through what is, in ordinary language, a vacuum.

If there be such an ether, the heat is conducted by it, just as by a wire or any other solid conductor, except that its conducting power is very feeble in comparison, and the conduction, therefore, much more slow. So that between conduction and radiation there is no difference of kind, but one of manner only. Thus, in conduction, the conducting body is usually limited in area, while in radiation it is unlimited, surrounding entirely the body giving off the heat.

It is only because the conducting power of air or "ether" is very low in comparison, that the term radiation is used instead of conduction. In fact radiation may be considered as a special case of conduction, in which the conducting medium has a low conducting power and entirely surrounds the heated body. This last restriction confines radiation entirely to liquids and gases, and it is generally confined to the latter, among which the ether may be counted as the rarest, using the word both in its literal and general meaning.

(24.) **Convection of Heat.**—Convection may also be considered as a special case of conduction, where the connecting medium is a liquid or gas, and the two heated bodies are connected vertically. The lowest particles of the liquid or gas being heated by ordinary conduction, become thereby expanded, and lighter than

the colder particles above; they consequently rise through them. The next row of particles, now the lowest, rises in like manner, and then the next row—and so on, until the whole body of the liquid becomes of the same temperature,—not, as in conduction, by the passage of heat through the body, but by the *conveyance* of heat by the particles as they rise.

To use the vibratory theory: in *conduction*, the end particles being set in vibration, communicate this vibration to the next particles, and these to the next, and so on; but in *convection*, the end particles, when set in vibration, move upwards, continuing to vibrate, and communicating this vibration not only to the next particles, but, in a less degree, to all the particles with which they come in contact, distributing over the whole body the heat which in conduction would be given only to the adjoining particles.

(25.) **Conduction of Heat.**—Communication of heat from one body to another by means of a third is called conduction, which comprises all cases whatever of such communication if the existence of the ether just mentioned be assumed, and if convection and radiation be considered as special cases of conduction.

(26.) **Variety in Conducting Power.**—Different substances possess this property of communicating heat in different degrees, metals being among the best, and air and elementary gases among the worst, conductors. The comparison of these is easily made by many methods. In the case of solids (to which the term *conduction* is generally confined) one method is by arranging pieces of different substance, of equal size, so that an equal amount of heat is communicated to each one in the same time.

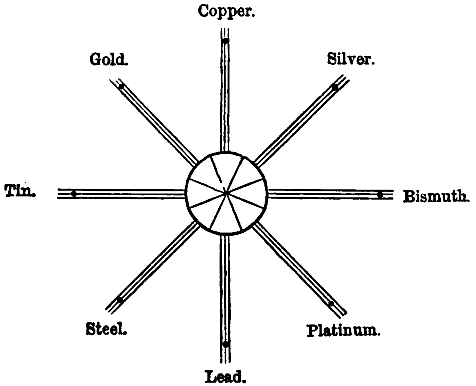


Fig. 47.

Thus, if I take equal pieces of silver, copper, iron, brass, gold,

tin, steel, lead, platinum, and bismuth, and arrange them as radii of a circle, at the centre of which they meet, and apply to this junction a spirit-lamp, each will receive in a given time an equal amount of heat. The comparative rates at which the heat travels may be shown in many ways. One is to place small pieces of phosphorus, of equal sizes, at the extreme points of these radii, and to notice the order in which they inflame, that which does so first having evidently received the most heat in the time.

Another method is to attach small pellets of metal or wood by wax to the extremities of the radii, and to note the times and order in which the wax of each melts from the heat communicated by conduction through the radii.

By tests of this kind it is found that silver conducts heat most readily, and that, taking this conducting power as unity, we have,—

Silver,	1.000	Tin,	0.145	Lead,	0.085
Copper,	0.736	Iron,	0.119	Platinum,	0.064
Gold,	0.532	Steel,	0.116	Bismuth,	0.018
Brass,	0.236				

It must be borne in mind that this does not represent the *amount* of heat received by each body, this being the same in each, but the *temperature*—*i. e.*, the amount not required to keep the body in vibration. So that at first this problem of conduction might seem to be but that of *specific heat* in another form, and therefore the heat ought to be conducted in a ratio inverse to the specific heats of the various bodies—*i. e.*, the less the specific heat of a body, the more of any given quantity should be available for melting the wax or igniting the phosphorus.

We have seen (p. 77), that in order of specific heats we have,—

	Specific Heat.	Conduction.
Copper, ...	0.0951	0.736
Tin, ...	0.0562	0.145
Gold, ...	0.0324	0.532
Lead, ...	0.0314	0.085

But the second column shows that conductivity and specific heat are not the same thing; for while the capacity for heat of copper is only three times the capacity of lead, its conducting power is nearly ten times as great. Also, while tin has a greater capacity for heat than gold, it is not so good a conductor. Neither are specific heat and conducting power in an inverse ratio.

Specific heats are measured by taking equal weights of different substances; their conducting powers are ascertained by taking equal lengths. Specific heat is measured by noting the total amount of heat given off by the whole body in a given time; conductivity, by noting the time required for a given temperature to be reached at a given distance from the point of application of heat. If we connect the specific heat of a body with its conductivity by means of its atomic weight and specific gravity, it will

probably be found that there is more connection between them than has hitherto appeared. This is discussed more fully in the chapter on **Conduction.**

(27.) **Inter-relation between Radiation, Conduction, and Convection.**—It was long the notion that heat was *conducted* by solids, *conveyed* by liquids, and passed by *radiation* through gases, it being supposed that heat passed through air and other gases without affecting them, or being itself diminished by such transit; but more careful observation and more accurate measurements have shown that gases, as well as liquids and solids, absorb heat, so that the term radiation really comprehends in its full meaning both *convection* and *conduction.* We may say generally that any two bodies brought into contact at different *temperatures* (not necessarily different heats), will gradually approximate their temperatures until they become equal. They will then, so far as heat is concerned, become one body, and this approximation of temperature will continue between any number of bodies.

If one of these bodies be a liquid, the conduction of heat goes on in precisely the usual way, excepting that if heat has to pass upwards through a liquid, the phenomena of convection interfere with the ordinary method of conduction, while, however, they very materially assist it. It takes a long time to pass heat through a liquid by conduction, but not nearly so long when convection occurs.

If one of them be a gas, especially air, oxygen, or hydrogen, the small quantity of the heat absorbed in its passage suggests at first the idea that it passes through entire as through a vacuum, but this arises from the small quantity of matter in the gas.

(28.) **Diathermacy.**—It may be said, generally, that no substance whatever is entirely *diathermic* (*i. e.*, allows heat to pass entirely through it), any more than any is entirely transparent. It is also worthy of especial notice that transparency and diathermacy seem to require different conditions, and to depend upon different structural arrangements.

Solids.	Diathermacy.
Rock-salt, ...	.92
Iceland spar, ...	.39
Plate-glass, ...	.39
Alum, ...	.09
Sugar-candy, ...	.08
Ice, ...	.06

These numbers show the ratio of the heat found to pass through a plate of each substance 1-10th of an inch thick.

Liquids, in strata of nearly 4 inches.	Diathermacy.	Gases, in strata of 4 feet each.	Absorption.
Colza-oil, . . .	.30	Air, ...	1
Olive-oil, . . .	.30	Oxygen, ...	1
Ether, ...	.21	Nitrogen, ...	1
Sulphuric acid, .	.17	Hydrogen, ...	1
Alcohol, . . .	.15	Chlorine, ...	.61
Water, ...	.11	Hydrochloric acid, .	.38

The decimals in the column for liquids show the amount of heat transmitted as compared with the whole amount falling on the end of the tube containing the liquid. Thus oil allows the transit of rather more than 2-3ds of the whole amount of heat, while through water only 1-10th can pass. The column of figures for gases shows that while air, oxygen, nitrogen, and hydrogen all allow nearly the whole of any heat falling on them to pass through, absorbing but a little, chlorine absorbs 39 times, and hydrochloric acid 62 times as much as these do. The experiments as yet made do not show the ratio of the absorption by gases to that by liquids and solids.

It will be well to get fairly into the mind what is meant by diathermacy, that it is the passage through any object, not of *matter*, but of *motion*. Thus, I place between myself and the fire a glass screen. I find it screens my face from the greater part of the heat, but that yet some heat reaches my face. How does that heat pass from the fire to my face? What is it that passes through the screen? The fire consists of burning coal; this sets the air in vibration; the vibrating air comes in contact with the glass screen, and sets that in vibration; the vibration of the glass sets in motion the air on the other side, and this is the heat I feel. This assumes that heat is the vibration of ordinary matter. If we assume the theory of an ether, then the burning coals set in vibration the ether in the air, and also the ether in the interstices of the glass.

But in either case, why does not the full amount of heat pass through the glass? What becomes of the intercepted heat? I arrange six marbles in a row, at intervals of one inch. One of them, the fifth, is much larger than the others.

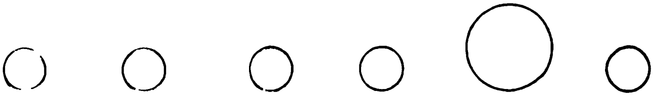


Fig. 48.

I propel the first marble against the second, this moves against

the third, the third moves the fourth, the fourth the fifth, and the fifth the sixth. But while the fifth, the large one, receives nearly the whole of the force I imparted to the first, it does not give the whole of this to the sixth, which is moved but slightly. The greater weight of the large marble requires more of the force to set it in motion. So the particles of the glass screen require more force to set them in vibration than the air, and therefore there is less force to act on the air beyond the screen.

But when the screen has been for some time exposed to this action it is heated to an equal degree, and is no longer a protection, but the reverse: just as the large marble, when fairly set in motion, would cease to be a protection to the small one beyond.

(29.) **Direction of Heat-rays.**—It being assumed that rays of heat pass off from every heated substance either by conduction or convection, it becomes now a subject of inquiry as to what direction these rays take, and what changes this direction undergoes, as well as by what means these changes may be influenced.

As to original direction, it may be simply said that heat, like light, passes off in straight lines from any heated body, and that the direction of these straight lines is perpendicular to the surface of the body. If there be a single point, then the heat-rays pass off in straight lines in every direction. If the body be a sphere, or any shape approaching the spherical, the rays also pass off in all directions from the surface, just as though from the point at the centre of the body.

These rays keep their direction unchanged so long as the medium through which they pass continues the same. If they enter a denser medium their velocity is retarded, if a lighter it is increased. If such entrance into either a denser or lighter medium be at right angles to its surface, *the direction* of the rays remains the same, but if not at right angles it is changed.

If a ray of heat strike upon a substance that it cannot penetrate it is reflected—that is, is bent back, just as a ball striking against a wall rebounds. If it fall upon the substance perpendicularly—*i.e.*, at right angles to its surface—it returns in the same line; if it fall to the right of this perpendicular it returns as much to the left of it, and *vice versa*.

The laws of Radiation, Reflection, Absorption, Refraction, are, in their general principles, the same for Heat, Light, and Electricity; in fact, the fundamental principles of all branches of Physics are the same, modified only by the nature of the especial facts. It is more than probable that when we know more about the various branches of the subject it will be found that Heat, Light, Actinism, Galvanism, Electricity, and Magnetism are but different phases of one great natural phenomenon, but the same harmony played in different octaves.

Since these laws of Absorption, Radiation, &c., are the same for all *branches of Physics, I have* thought it better to discuss them

ones for all. I have therefore devoted a chapter to the subjects, Conduction, Convection, Absorption, Radiation, Reflection, Refraction, Transmission, and Polarisation, in which will be found both the general theorems and the facts special to each branch of the subject.

[illegible] **Latent Heat**—*Liquefaction.*—I have before spoken of heat as being a phase of energy, and shown that any given amount of energy must produce a result in some form or other. The normal result is heat or motion, and two very familiar instances may be quoted in which the energy applied in the form of heat may entirely disappear, as heat being wholly converted into motion. If I rub two pieces of wood vigorously together, the motion becomes entirely converted into heat. If I place a piece of ice near a fire, heat is entirely converted into motion—*i.e.*, *the ice melts, but does not get warm.*

I place a pound of ice at 10° C. before a fire, and a thermometer in it. It rises in temperature up to 0° C.—say in ten minutes. In another ten minutes it might be expected to rise to 10° C., but it continues at 0° C. until the whole is melted. All the heat that falls upon it during the melting is entirely lost as heat, but is evident as motion, since in melting the particles vibrate, and are loosened from the crystallised form. How shall I measure the amount of heat that is so used and converted from heat to work? There are several ways of doing this. If, when the pound of ice is wholly melted, and before the water so formed begins to warm, I place beside it a second pound of ice at 0° C. (*i.e.*, just beginning to melt), I can compare the results, and obtain the answer to my question. I let the ice and water remain under the action of the heat until the second pound of ice be also wholly melted. It will not be warmed any more than the first pound was. But what is the temperature of the water? I find it to be 79° C. That is, the same amount of heat that was required to melt the pound of ice, without any increase of temperature, suffices to raise the water beside it from 0° to 79° C.

Again, I mix a pound of water at 0° C. with a pound of water at 100° C., and I get two pounds at 50° C.—*i.e.*, the mean temperature. I now add a pound of water at 100° C. to a pound of ice at 0° C., and I get still two pounds of water, but not at a temperature of 50° C. The water resulting from the mixture of ice and water is only about 10.5° C. The difference between 50° and 10.5° for two pounds is equal to 79° for *one* pound, and is, as we have seen, the amount of heat required for the liquefaction of the pound of ice.

Again, if, using the Fahrenheit measurement, I mix a pound of water at 32° F. with a pound of water at 212° F. (*i.e.*, at the freezing and boiling points, as before), the result will be two pounds of water at 122°—that is, the 212° in one and the 32° in the other will be added together and equally divided:

$212° + 32° = 244°$; and $244° \div 2 = 122$. But a pound of *ice* at 32° and a pound of water at 212° will give two pounds of water at 51°. Here $122° - 51° = 71°$; and 71° for one pound represents 142° for two pounds.

So that the amount of heat required to liquefy one pound of ice, without producing any increase of temperature, is just the amount that would raise one pound of water from 0° to 79° C., or from 32° to 174° F. Or, conversely, it would raise 79 lb. of water 1° C., or 122 lb. of water 1° F.

It appears that in passing from the solid to the liquid condition of matter, water absorbs, as it were, a large amount of heat, which entirely disappears, except in its effect in producing liquefaction.

The term "**Latent Heat**" is applied to heat so absorbed, and seems to be appropriate, because the heat so absorbed is only latent, and is given out again if the water be refrozen.

The question will at once occur, "Is this a phenomenon peculiar to water, or is it general to all substances?" Experiment shows it to be general, though the latent heat is greatest in the case of water. Zinc absorbs 28 units of heat, silver 21, tin 14, sulphur 9, phosphorus 5, mercury only 2. By "unit" I mean the amount of heat required to raise one pound of water from 0° to 1° C. By "absorbing" so many units, I mean that in passing from the solid to the liquid condition the given body uses up, as it were, so much heat without any consequent rise in temperature.

Vaporisation.—The question will next present itself, "Are there, when a liquid is evaporated, any phenomena corresponding to the 'latent heat' of liquefaction?" When a solid becomes a liquid, a larger or smaller amount of heat is required for the conversion. Is heat required in the same way for the conversion of a liquid into a gas? We find, by appealing to experiment, that not only is heat absorbed as in liquefaction, but that the absorption is much greater in amount.

How can I estimate the amount? By the same method as before? I can place steam at 100° C. and water at 100° C. together, expose them to equal heat, and shall find the steam to rise in temperature while the water is becoming steam without such increase. But the experiment is complicated by the necessity of confining the steam, which would otherwise diffuse itself over the whole place. I can, however, work out the problem in a more simple manner. I place a pound of water at 0° C. over an equable source of heat, and note the time required to raise the water to 100° C., and also the further time required to convert the whole of it into steam. Let it take one hour to raise it to 100° C.—*i.e.*, to the boiling-point. It will not immediately become steam, but will require more than five hours longer, the supply of heat being regular, for the whole of it to be evaporated. The amount of heat required to convert a pound of water at 100° C. into steam will be found to be 535 units of heat. If water did not become *steam until a* very high temperature, say 700° C.,

then a pound of water would be raised to 637° C. by the heat that now converts it into a pound of steam at 100° C., all beyond the first 100 units becoming latent heat.

In speaking of the latent heat of liquefaction, we noticed that water had a greater capacity for latent heat than any other body, in passing from the solid condition to the liquid, and I enumerated the amounts of heat converted into force in the case of several elements—zinc, silver, tin, &c. I cannot do this in comparing the latent heat of water and other liquids when evaporated, for the only liquid element, mercury, does not boil but at a very high temperature, and the elements that we are familiar with, as gases, can only be liquefied by great trouble and complicated apparatus. I cannot, therefore, compare the boiling-points and corresponding latent heats of several elements as I did their melting-points.

But I can compare the latent heat at evaporation of many compound bodies which are familiar to us both in their liquid and gaseous states. Thus, alcohol has a latent heat, at evaporation, of 202, ether 90, bisulphide of carbon 86, perchloride of tin 30; these figures expressing the fact that at evaporation so many units of heat become latent—*i. e.*, are converted into work.

In both tables water stands first, as having the greatest capacity for latent heat—*i.e.*, as requiring more force to melt and to evaporate it than any other body, simple or compound.

(31.) **Latent Heat compared with Specific Heat.**—I have shown (p. 61) that if two equal quantities of gas be placed side by side, exposed to the equal action of the same source of heat, but one at liberty to expand and the other unable to do so, then they increase in temperature at unequal rates. The gas whose *pressure* is constant only rises 10°, and increases in volume; while the gas whose *volume* is constant increases about 14°, but, of course, does not expand. What becomes of the force that in the one case is evident, and in the other latent? The answer is evident. It is converted into motion, moving the atoms of the expanding gas.

Let us trace this latency of heat through the changes of condition and of temperature. In the solid state, the heat applied separates and moves the particles and raises the temperature. The portion of the heat that increases the temperature is evident as heat; that which separates and moves the atoms of the body is not evident, and may be termed *latent*. As we rise towards the melting-point of the solid we find that less of any heat applied is evident as temperature—*i. e.*, more of it is latent. The same is true of liquids. As we pass from the melting towards the boiling point, we find more and more of the heat applied to be latent—*i. e.*, doing work in expansion, and less to be evident as temperature. We find also that more of the heat is latent when applied to the liquid than when applied to the solid; and, likewise, that the amount latent increases more rapidly as we ap-

proach the boiling-point than when with the solid body we approached the melting-point. That is, more work is done, more motion effected, in boiling the liquid than in melting the solid.

To sum up: I take a very solid lump of ice, at a very low temperature—say, 20° C.—and expose it to the action of a steady fire. The heat plays round it, as it were, unable to effect an entrance, and is almost all given off again as temperature. Gradually it finds its way within, the particles begin to be slightly loosened, and less of the applied heat acts on the temperature. This rises until it reaches 0° C., and then the whole heat is devoted to melting—*i. e.*, doing work, causing motion.

This may be represented thus:—

−20° C.

Most of the heat is given off as temperature.	But little of the heat causes motion.
This amount continually diminishes until	This amount continually increases until
None of the heat affects the temperature.	All the heat is devoted to producing motion.

0° C.

This is repeated with the liquid as it rises to the boiling-point. From 0° to 100°, more and more of the heat applied is given to the production of motion, and less and less to the increase of temperature, until at 100° all is given to motion, and none to temperature.

(32.) **Latent Heat connected with Radiation.**—But a thoughtful reader may ask me, Why is this? Why is all the heat devoted to motion at 0° and at 100°, and only partially at other points? Why are the ordinary laws of exchange and of radiation at fault here? The answer is that they are not at fault—they are in full operation throughout; the result, which seems to be a suspension of them, exists really because of their operation.

To put a parallel case: A careful man and a spendthrift agree to an equal division of property, and to preserve the equality for some time. In a very short time the spendthrift has disposed of his share, and a second division takes place, followed by a third, a fourth, and many others, each of less and less amount, because of the diminished total, until the last coin being divided and spent, both are penniless. So with the ice and warm water: there is a perpetual division of heat between them; but the ice when at 0° is just on the point of being entirely loosened and separated, and all the heat it receives is converted into motion. This renders a redivision continually necessary so long as any warmth, above 0°, remains in the water. The ice is the

parallel of the spendthrift, continually converting its heat into motion, as he dissipated his money, and calling upon the water for more, as he did upon the careful man, whose thrift provided him with means of dissipation.

The same comparison holds good for the latent heat of steam. There is a continual division and redivision of heat between the water and the steam.

(33.) **Heat converted into Work.**—We see, then, that "latent heat" means no more than that heat becomes motion. Can we make this more evident? Can we by means of heat effect motion in a way that we can appreciate more distinctly than we can the inter-molecular motion of melting ice or boiling water? The answer is very clear and easily understood. The motion that is so very palpable on our railways, in our steamers, and the work done by our stationary engines in pumping, sawing, &c., is all derived from heat. Water is made into steam by means of heat, and the force contained by the steam, derived from the heat, is the force which does the work.

(34.) **Mechanical Equivalent of Work.**—Have we any means of calculating the ratio of work to heat? That is, can we tell beforehand how much work will be done by a given amount of heat? Conversely, how much heat will be required to produce a given amount of work?

The two questions are one, and that one a question that required long and patient investigation; but it has been answered very completely. The amount of heat that will raise 1 lb. of water from 0° to 1° Fahr. will also raise that weight of water 772 feet. Or, to express the same fact in Centigrade degrees: the amount of heat that will raise 1 lb. of water from 0° to 1° C. will also raise the same weight of water 1390 feet.

Instead of raising 1 lb. of water through a distance of 1390 feet, we may raise 1390 lb. of water through a distance of 1 foot; or 695 lb. 2 feet; or 139 lb. 10 feet; or any other weight a proportionate distance.

To put this into other words: a weight falling 1390 feet will raise 1 lb. of water from 0° to 1° C. *if* (and this is the difficulty) all the force be brought to bear upon the water, without any loss. How can this be done? Mr Joule (to whose researches we owe most of our definite knowledge of this subject) did it by connecting a set of paddles, revolving in a vessel of water, with a roller, so that the revolutions of the roller set in motion the paddles. The roller was set in motion by a weight fastened to it by a cord. The falling of the weight moved the rollers; the movement of the rollers set the paddles in motion; the motion of the paddles raised the temperature of the water. From this it followed that the descent of the weight warmed the water. Mr

ɜ found that the greater the descent of the weight, the greater ɾarmth of the water, and that the descent of 1 lb. 1390 feet d 1 lb. of water from 0° to 1° C. This has therefore been ɔted as the "unit of heat." When a "unit of heat" is spoken ıe term means that amount of force which, in the form of will raise 1 lb. of water 1° C., or will raise 1 lb. to a height 90 feet.

SUMMARY.

A SOLID body can be made liquid, and a liquid body made gaseous, only by the application of heat. Conversely, a gas may be made liquid, and a liquid solidified, by the abstraction of heat. But we are not able, in all cases, to apply or abstract the heat to the required degree. Page 57.

Heat applied to a gas increases its temperature and its elasticity. Page 59.

Heat applied to a solid tends to separate its particles, to raise its temperature, and to increase its volume. Page 60.

Heat applied to a liquid raises its temperature and tends to increase its volume. Page 60.

With a few apparent exceptions, *all bodies expand upon being heated.* Page 61.

All bodies, upon the application of heat, have their temperatures raised—*i.e.*, give off more heat. Page 62.

The sources of heat are mechanically varied, but may be summarised by saying that anything which *diminishes the volume* of a body is usually a means of developing heat. Also, to *prevent motion* is to develop heat. Page 62.

Heat can be measured only by its effects. Expansion of volume is the effect most easily appreciated. Page 64.

The Thermometer is an instrument in which the expansion of mercury marks the increase of temperature. Page 65.

The Pyrometer is an instrument for measuring very high temperatures, at which the thermometer would fail. Page 67.

The Thermo-pile (together with a galvanometer) is used for the detection and measurement of very small amounts of heat. Page 68.

Heat is a phase of energy or force. All energy tends to produce motion. If this motion be prevented, heat is the form the energy takes. Page 69.

Heat is governed in its transference by the same laws of *Reflection*, *Refraction*, *Radiation*, &c., as **Light**. Page 70.

The capacity for heat of a body is the amount of heat it requires to produce any given effect of heat. Generally, the capacity for heat varies inversely with its density. Page 73.

The capacity for heat of any substance is greatest when it is in

the liquid form. It is also greater at a high than at a low temperature, whether the body be solid or liquid. Page 75.

The specific heat of **an atom** is probably the same for all elementary substances. Page 79.

Heat **is radiated** in all directions from all bodies. Page 80.

The **radiation of heat** through a *solid* is called conduction. This conduction is performed at different rates in different substances. Page 81.

Heat falling upon a plate of **rock-salt** almost entirely passes through it. Rock-salt is therefore called **diathermic.** All bodies are partially diathermic. Page 83.

Heat falling upon ice at 32° F. (0° C.) does not warm it, but is entirely spent in melting it. Heat so ceasing to be evident as heat is called **Latent Heat.** Page 86.

As much heat is used to melt 1 lb. of ice as would raise 1 lb. of water 79° C. The **latent heat of water** is therefore said to be 79° C. or 122° F. Page 86.

Heat falling upon water at 212° F. (100° C.) is entirely spent in converting the water into steam, and does not increase its temperature. As much heat is spent in converting 1 lb. of water into 1 lb. of steam as would raise 1 lb. of water 535° C., or 535 lb. of water from 0° to 1° C. **The latent heat of steam** is therefore said to be 535° C. or 963° F. Page 87.

The **latent heat of water** is greater than the latent heat of any other liquid, and the **latent heat of steam** is greater than that of any other gas or vapour. Page 88.

At 0° C. all the heat falling upon ice is latent; below that temperature only part of the heat is latent, and the lower the temperature the less of latent heat. Page 88.

Between 0° and 100° only a part of heat falling on water is latent, and the proportion increases with the temperature, until at 100° the whole heat becomes latent. Page 89.

The term **specific heat** is the technical expression for the ratio between the heat that is latent and that which is apparent. Page 89.

The phenomenon of **latent heat** is *not* an exception to the law of *radiant heat.* Page 89.

Heat can be converted into *motion* or *work.* Page 90.

The amount of *motion* or work that heat can be converted into is called **its Mechanical Equivalent.** One degree of heat (1° C.) is equivalent to the work of raising 1390 lb. 1 foot, or 1 lb. 1390 feet. Page 90.

LIGHT.

(1.) **Introduction.**—If a room be darkened, nothing in it will be visible until some source of light be introduced. A red-hot poker brought in will give out light that will radiate throughout the room, and render objects in it dimly visible. A candle will do this in a greater degree. It seems, therefore, that it is not enough for an object to be presented to the eye for it to be seen, but that the agency of light is essential. Light must proceed from any object to the eye, before that object can be seen. To understand what is meant by seeing, it is necessary, therefore, to know something of the nature of light; for of all our senses no other is so likely to mislead us, if we are ignorant of its nature, as that of sight.

(A.) The varieties of light are—

1. *Sunlight,* including the light from the moon and planets.
2. *Light derived from heated solids.*
3. *Light derived from electricity.*
4. *Phosphorescent light.*

Sunlight is sometimes spoken of as natural light, whilst such as gas-light and candle-light are spoken of as artificial. But the light of the sun does not differ from other light, except in coming from a source entirely beyond our control. It is more than probable that light, from whatever source it is derived, is the same as to its nature and properties. Of this nature we can judge only by these properties.

1. *Sunlight.*—Of this we cannot say positively what it is.

2. *Light from Heated Solids.*—If any solid body have its temperature continuously raised, it will eventually become luminous (except it melt before it reaches the luminous point). Most solids emit light at a temperature of 1000° F. As the heat increases, the colour passes through regular gradations. The *natural colour* of the body changes to red, orange, yellow, white,

and at the highest temperature to white slightly tinged with violet. This may be shown by means of an ordinary poker heated in a fire.

3. *Light from Electricity.*—From electricity we can get light either as sparks or as a constant light of great power. If a galvanic-battery current be sent through two metallic wires, the points of which are near together without touching, a light will be emitted, depending for its strength upon the power of the battery. If the metallic wires terminate in two carbon points, the light will be the purest known, not excepting the light of the sun.

4. *Phosphorescent Light.*—Specimens of this are the light of the glow-worm and fire-fly.

(B.) Light proceeds from its source in straight lines, and in all directions. If a single light, such as a candle, be placed in a room otherwise dark, a person standing in any part of the room can see it, if there be nothing between it and the eye. It follows, therefore, that light proceeds from the candle to every part of the room, though the light is weaker as the distance increases. The rays of light spread out in a fanlike manner, so as to fill up more room, and the intensity of the light is therefore diminished the farther it goes.

Light has the power of penetrating most substances ; or, in other words, its nature is so ethereal that it can find its way through the pores of even the densest substance. No substance is completely transparent—*i.e.*, will allow all the light falling on it to pass through. No substance is completely opaque—*i.e.*, stops all light completely. In other words, light can find its way through the finest openings imaginable, while even the most rarified substance is sufficiently solid to stop some of any light falling upon it from passing further.

Light that falls upon any substance without passing through it—*i. e.*, that portion of light which the substance intercepts—is either destroyed altogether or reflected. Thus light falling upon a thick black curtain, especially of velvet, is almost entirely destroyed. The term "absorbed" is frequently used for this effect ; but until it can be shown that the light so "absorbed" can be recovered by any process, it may be said to be destroyed. But if the surface, instead of being dark and rough, be light-coloured and smooth, the light will be reflected or bent back so as to be still capable of exercising all the usual effects of light, but having its direction changed. This is familiarly illustrated by a ray of light thrown on a mirror of glass or highly-polished metal plate. The light falling from a candle on the surface of a looking-glass is almost entirely reflected, and is sent back from the glass to the eye, so that an image of the candle is seen behind the glass, in the line in which the light comes from the glass to the eye.

The light that does *pass through* any substance is affected in

direction by the density of the substance, and also in its velocity. It would seem that in passing from a thin medium, such as air, into a denser, such as water, the ray of light has more difficulty to contend with. It is retarded, and is forced out of its original line of direction into another. If a ray of light were made to pass through successive strata of ice, water, quartz, and glass, it would be found that at each change of medium the velocity of the light would be decreased, and its direction changed: in passing from the air to the ice, its velocity would be slightly diminished and its direction changed a little; in passing from the ice to water the retardation and change of direction would both be increased; and this would be still more the case when the light passed from the water to the quartz, and from the quartz to the glass.

One remarkable instance of this is the passage of light from the sun, moon, stars, &c., to the eye of an observer on the earth. The air extends some forty miles above the earth. Of the whole mass thus surrounding the globe, three-fourths of its quantity is within five miles of the earth, the remainder being so much the more attenuated. The lowest portion has to bear the weight of the air above it, and is therefore more compressed. The whole forty miles of air may therefore be considered as very rare at top, and, comparatively, very dense at bottom, the density continually increasing from above downwards.

Now, if the density were the same throughout, a ray of light on entering would be deflected from its original direction, but would pass through the air after deflection still in a straight line; but as the density increases continually, the light is continually more and more deflected; and the result is, that light on entering the air proceeds not in a straight but in a curved line. But the image is presented to the eye of the observer as though it came in a straight line, and in the particular straight line of which the last points of the curved line formed a part. In this way we see the sun before it rises, and also after it has set, because the rays of light which would, if they continued in the straight line in which they left the sun, pass over our heads, are bent down by the increasing density of the air until they reach the eye.

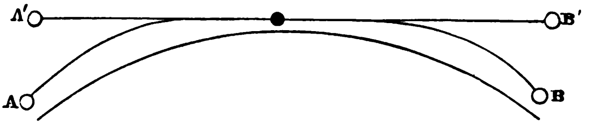


Fig. 49.

A, real position of the sun when set. A′, apparent position, still visible.

B, real position of the sun before rising. B′, apparent position, already visible.

Again, the refraction of sunlight by the air is the cause of twilight.

The rays that are bent down (as just described), but not sufficiently so to reach the eye, are reflected by any surface which they meet, and so ultimately reach the eye as scattered light.

(C.) If a ray of ordinary light passes through a medium of which the surfaces are not parallel, the refraction is of an especial kind, and presents very singular results. This is shown most remarkably by the use of a triangular prism. On quitting a prism through which it has passed, a ray of light does not take a path parallel to its original direction, but is diverted from it still more. But in addition to this increased divergence of direction, the ray of light now possesses the remarkable property of being spread out like a fan, not as in any case of light merely occupying more room, and becoming consequently weaker, but the light is decomposed (*i.e.*, ceases to be ordinary light), and its constituent rays are spread out, so that each is separated from the other. Thus an ordinary ray of light becomes divided into seven rays, each differing from the original ray in colour. Each of these elementary rays has a distinct colour of its own, and white light seems to be compounded of these various colours. These elementary colours are red, orange, yellow, green, blue, indigo, and violet. Another theory, however, asserts red, yellow, and blue to be the only primary colours; and that orange, green, indigo, violet, and all other colours, are compounded from these.

V	Violet.
I	Indigo.
B	Blue.
G	Green.
Y	Yellow.
O	Orange.
R	Red.

Fig. 50.

The simplest way of observing this decomposition of white light is to admit a single ray of light into a dark room (for instance, through a small hole in a shutter), and allow it to pass through a prism of glass. The light will then fall on the wall, or any screen placed to receive it, not as ordinary white light spread out, but with its constituent rays separated from each other, and succeeding each other in the order, red, orange, yellow, green, blue, indigo, and violet, so that they form a series of bright spots arranged in the form of a parti-coloured strip of light with parallel straight sides and circular ends. If the prism be removed, the light entering through the shutter-hole will fall as ordinary white light on the screen or wall, and form a circular disc of light varying in size with the distance of the screen. As often as the prism is placed so that the light has to pass through it, so often will the white light be broken up into its constituent rays, and the light on the screen become a parti-coloured strip. If, instead of removing the prism, we add another to it, so that the two together make a stratum of glass with parallel sides, then the effect of the second counteracts the effect of the first, and the result is the same, very nearly, as if no prism were present.

The white light that was decomposed by one prism will be recomposed by the other, and, after passing through both, will fall upon the screen as white light in a circular disc, just as if no prism was in its way, *excepting that* the position of the disc will be some-

what changed by the refraction of the ray of light passing through the glass.

The peculiar appearance which the sunlight falling upon rain-drops presents in the phenomenon of the rainbow may be explained by these facts of refraction. For a person to see a rainbow, he must be between the sun and the falling rain. The rain-drops each receive a ray of light, which is refracted and reflected according to the ordinary laws of refraction and reflection. By the refraction the light is broken into rays of the various colours constituting white light. Any person standing in such a position that his eye receives the light from several of these rain-drops on which the sun is shining will get from one drop a ray of red light, from another an orange ray, from another a yellow ray, from the next a green, and so on; the beauty of the rainbow depending upon the clearness with which these various refractions are effected.

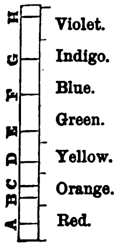


Fig. 51.

The continuance of the rainbow depends upon the continuance of sunshine and of rain. In the case of the rain-drops, as each drop passes away another takes its place and effects the same refraction, so that a succession of rays continues to fall on the eye.

(D.) If a very narrow opening with straight sides be made in the shutter, instead of a round hole, and the light allowed to pass through a prism as already described, the screen will receive as before a parti-coloured strip of light with straight parallel sides and circular ends. In this the colours will succeed each other in the usual order of red, orange, yellow, green, blue, indigo, violet. If this strip of light be examined carefully with a magnifying-glass, it will be found that the light is not continuous, but that it has intervals of darkness too minute to be observed by ordinary eyesight. If examined with sufficient magnifying power, more than two thousand of these intervals of light may be observed, having the appearance of dark lines crossing the spectrum of very various widths.

Some few of these lines are much wider and more easily observable than others, and are distinguished, for convenience of reference, by the letters A, B, C, D, &c. Eight lines are so distinguished, beginning at the red end of the spectrum. In the red is a line A; in the orange, lines B and C; in the yellow, a line D; in the green, a line E; near the junction of the green and blue, a line F; towards the indigo, a line G; and towards the extreme end of the violet, a line H. These lines divide the spectrum into parts in a manner very convenient for reference.

(E.) Light travels with so great a velocity that it requires to traverse an immense distance before we can take any note of the interval. Its speed is such that it could encircle the earth eight times *in a second, so that* it is difficult to measure its velocity between

any two points on the globe. Fortunately, however, we are able to estimate the time it takes to come from some of the sources of light in the heavens whose distances we know, and in this way we arrive at a tolerably accurate estimate of its velocity. Notably so in the case of Jupiter's moons, in which it is found that their light takes about fifteen minutes to traverse the diameter of the earth's orbit round the sun—*i.e.*, if we are on the side of the sun nearest the planet, we get the light from its moons fifteen minutes sooner than when we are on the side of the sun farthest from it. It follows from this, that light takes fifteen minutes to traverse a distance of 182 millions of miles. Its velocity, therefore, is 12,133,333 miles per minute, or 202,222 miles per second. Speaking generally, the velocity of light may be said to be 200,000 miles per second.

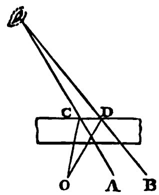


Fig. 52.

(F.) If we look at any object through a piece of glass, we see it apparently in a place that we know to be more or less not its true place, owing to the refraction of the light by the glass. If now we look at it through a piece of Iceland spar (which is a crystal of carbonate of lime), or any transparent crystal, we shall see not only one, but two images. This is because this particular crystal possesses the power of doubly refracting light. Thus, having selected some small object, O, for observation, if we look at it through a piece of this crystal we shall see it in duplicate, because the light passing from the object through the crystal to the eye comes in two different lines, dividing immediately it enters the crystal, and partially reuniting on the retina of the eye. As these two lines come to the eye from different points of the surface of the crystal, we see an image in each line, and the result is the same as if we saw two objects, one at A and one at B.

This has a parallel in the case of sound. If a very long bar of iron or wood be struck, say with a hammer, at one end, a person at the other end may hear the sound of the blow twice. If the ear be held close to the bar, one sound will come through the bar and another through the air, and thus the sound of the same blow will be heard twice. In the same way, in a case of double refraction, the same object sends two rays of light to the eye, each in a different direction, and the result is the same as if two objects were seen.

If, however, the crystal be held in one particular position, only one image will be seen. It will be noticed that some of the edges of the crystal are sharper, and others more blunt, than the remaining edges, which are sometimes what is called square-edged. If we hold the piece of spar so that we look through it from one corner of one blunt edge to the opposite corner of the other—*i.e.*, so that the ray of light pass from the object to the eye through

these two corners of the blunt edges—it will show only one object. This line is called the optic axis of the crystal, and is, as it were, the natural centre of it, round which its parts are arranged symmetrically.

If we place another piece of spar beside the first, and look at the same object as before, we shall, as before, see two objects, but they will be farther apart — *i.e.*, the second piece of spar will not again divide each ray of light, but will refract them according to the ordinary laws. But the two crystals may be so placed that the effect of one shall correct that of the other, and one image only be visible through both.

(G.) We have seen that light, when it comes in contact with any substance whatever, is affected more or less in its direction, velocity, and composition. In direction it is diverted from its original course to one making an angle with it which is greater as the density is greater. In velocity, it is retarded if the density be increased. In composition, it is affected by passing through any substance of which the sides are not parallel. These properties of light render it susceptible in an exceedingly delicate degree; and for a ray of light to pass directly from one object to another in a straight line, without being affected in any way, is a very rare occurrence.

But the laws which govern these modifications of direction, velocity, and composition are now well known, are simple in character, and easy of comprehension.

If a ray of light fall directly perpendicular upon the smooth surface of a glass plate, it passes through it without being in any way affected otherwise than by having its velocity retarded during the time of passing. But if it fall obliquely, it is bent out of its path by refraction. This refraction is the greater the more obliquely it falls on the glass, becoming nothing in the case of a perpendicular ray, which is affected equally on all sides, and therefore continues its course. But if the glass be covered behind by a coating of quicksilver, as in an ordinary looking-glass, the light, instead of passing through, is reflected. If it strike perpendicularly, it comes back in the same line; if it be oblique in its direction, it is reflected obliquely.

So that, whether the light pass through or be reflected, if it be perpendicular to the surface on which it falls it continues in the same straight line, either going on or returning. If it be oblique, it has its direction altered whether it be reflected or transmitted, and the alteration is the greater the more it varies from the perpendicular.

The law of reflection is very simple. Light reflected leaves the surface as much on one side of the perpendicular as its original direction is on the other side.

The law of refraction is equally simple in its nature, but not so easily expressed in simple language. But by the aid of a diagram it may be readily understood.

A c is a ray of light falling through air on a plate of glass at c, when it is changed in direction to c B. If I draw the line a from A c, and the line B b, both at right angles to the surface $a\ c\ b$, and so taken that the distance $a\ c$ is equal to the distance $b\ c$, then I find that the line b B is very much greater than the line a, also that the hypothenuse c B is much greater than that of the smaller triangle. If I draw the two perpendiculars so that the part c B shall equal the part cut off from c A, then $c\ b$ will be much smaller than $a\ c$. It is found that these two lines $a\ c$, $c\ b$, *have always the same ratio for the same substance*, when I cut off equal parts from the incident ray A c, and the refracted ray B c. I will enunciate this **law of refraction**, and discuss it more fully, in the chapter on Refraction.

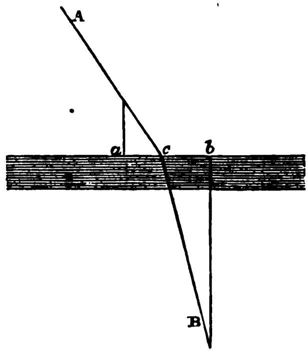


Fig. 53.

(H.) The effect of light upon the eye lasts for an appreciable interval of time. If I whirl round a point of light, say a spark at the end of a burnt stick, it is visible as a ring of light, provided I move it somewhat rapidly, for the light coming from any point of the circle remains visible (*i. e.*, its effect on the eye continues) until the spark get back to that point again. Just as a man might keep a number of spinning-tops in continual motion by giving each in succession a fresh impetus before it came to rest, so each point of the curve of light emits a fresh ray of light before the preceding one, from the same point, has ceased to affect the optic nerve. Just in the same way as the stomach is kept continually at work by food taken at intervals, so any given optical effect may be made to appear as permanent, though its source is intermittent.

The composition of white light may be illustrated by this means. If I colour a circular disc so that it represents the elementary colours in their normal proportions, I may, by whirling it rapidly round its central point, cause the light from each colour to fall upon the eye in succession from each point of the space occupied by the disc.

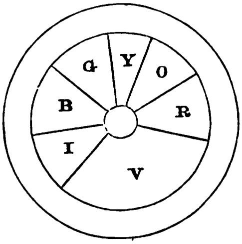


Fig. 54.

Thus, supposing a ray of red light to come from the space R, this space is immediately after occupied by the portion O, emitting orange light; and then by the portion

Y, emitting yellow light; then by the portion G, emitting green light; then by the portion B, emitting blue light; then by the portion I, emitting indigo rays; lastly, by the portion V, emitting violet light. These rays succeed each other so rapidly that the eye retains each impression during the impact of the others, so that it really sees all the colours on every part of the disc, and the result is that the disc appears more or less of a simple white colour.

(2.) **Velocity of Light.**—The rapidity of light is exceedingly great,—so great that the numerical expression of it altogether fails to convey any adequate idea. To say that light travels at the rate of about 200,000 miles per second, gives us a notion that its speed is enormous; but so would the figures 20,000 or even 1000. Standing at a small railway station, I see an express train rush by, and it is difficult to imagine a transfer of matter taking place much more rapidly. Yet I know that the speed of the fastest express train does not even approximate to a hundred miles per hour; while I am told that a ray of light would traverse this same distance (100 miles) *two thousand times*, not in an hour, *but in a second.* "The swiftest bird, at its utmost speed, would require nearly three weeks to make the tour of the earth; light performs the same distance in much less time than is required for a single stroke of its wing."

If the speed of a ray of light be so inconceivably great, it may well be asked, How is it possible to measure it? How can I estimate the time required to pass from one point to another, when the whole globe can be surrounded by a ring of light ten times in a second? To measure the progress of such a courser, we need, not the surface of the earth, but boundless space itself; and it was not until an opportunity occurred of tracing the path of light across the wide heavens that its velocity was even approximately ascertained. Astronomers, by means of the eclipses of the moons of Jupiter, have been able to measure the lapse of time required for light to pass across the orbit of the earth, about 190 millions of miles.

In the accompanying diagram S represents the sun, E and E′ two points in the orbit of the earth, and J the position of the planet Jupiter. When the earth is at E′ the light from Jupiter has to

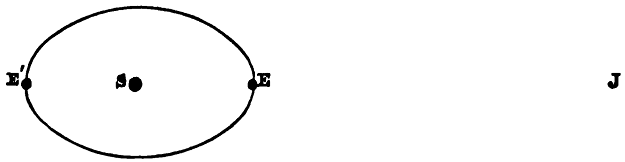


Fig. 55.

pass from J to E′ to reach the earth, but when the earth is at E, this light has only to traverse the distance J E—*i. e.*, just the dia-

meter of the earth's orbit less. The time required to traverse the extra distance has been found to be rather more than a quarter of an hour. Light therefore travels about 200 millions of miles in twenty minutes, or about 10 million miles in one minute.

(3.) **Measurement of Light.**—We measure heat by the amount of work it can do in a given time. We measure electricity, galvanism, magnetism, in the same way, by means of the practical results to be obtained by their use. But with light this is not so easy. One method (and a very accurate one) is to judge by the eye when two images are of equal brilliancy. Thus, if I wish to judge of the comparative power of two lights, such as two candles, I place them so that the images they respectively produce in a mirror shall be equal. For this to be done, the distance of the greater lights from the mirror must be greater than the distance of the lesser light. When I have arranged the lights so that their images in the mirror are of equal brightness (for this brightness is the only thing to be considered), I measure their distances from the mirror. If the distance of the greater be four times that of the less, then their powers are as sixteen to one—*i.e.*, one is sixteen times as bright as the other; if the distances be as three to one, then the powers are as nine to one; and generally, if the distance be D and D′, then the powers of the lights are as $(D)^2$ to $(D')^2$.

In this method we have to judge when the two images are of equal brilliancy, so that there is a certain margin of error to be allowed for. Sir John Leslie arranged a *photometer*, by means of which the two equal lights are brought into actual contact. Thus, at the ends of a trough, some feet in length, he placed the two lights whose brilliancy he desired to compare. A screen, (D E,)

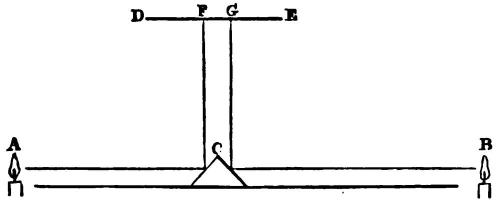


Fig. 56.

stood beside the trough, and the lights were reflected on to this screen so as to be side by side and in actual contact, by means of two mirrors at 90° to each other, and at 45° to the side of the trough. The light B was reflected from C to G, and the light A from C to F. If the lights A and B were equal, the screen was equally lit up at F and at G when the mirror C was exactly intermediate; but if they were unequal, the mirror had to be moved towards the lesser light, until the screen was equably illuminated.

The distances A C and B C when squared would give the relative powers of A and B.

(4.) **Persistence of Light.**—I take a small card, with one or two lines of printing on it, and fasten it loosely to the end of a penholder by a pin through its centre. I make it revolve smartly, and each line of print becomes an ornamental black ring. I see all the letters of each row at each point of a circle, and the variety of shapes gives to the ring so formed a number of projections, and the card itself becomes apparently a circular disc, with a number of external projections. I cut a narrow slit, say a quarter of an inch in width, on one side of the card, from the edge to the centre, and set the card rapidly in revolution. On looking through the slit, I find the card to be transparent (somewhat after the manner of coarse muslin). Whatever I see through the slit, I see also, as it were, through the card, for the images remain on the eye during the interval of time that the objects are obscured by the card.

(5.) **Sources of Light.**—If I heat gradually any solid substance, it becomes at high temperatures more or less luminous (unless it vaporise), generally passing through gradations of colour from red to white. If the substance become a gas before reaching the heat required to make it luminous, this gas may be heated to a very high degree without emitting light, but this is probably because the atoms of the gas are so small that the light from each one is too little to be perceptible by our organs of sight. This may also explain why gases are invisible under ordinary circumstances.

It seems, therefore, that light is but a mode of heat, just as heat is said to be a "mode of motion." It is clear that there is a connection between heat and light, though it is also clear that they are not identical. The sun's rays contain both light and heat, and these can be separated very easily and completely.

But light itself can be decomposed, and when so decomposed, it is found that the component rays have differing degrees of velocity in their vibrations. May it not be that (just as heat gradually becomes luminous) as it increases, so the heat-rays of the sun become luminous when the number of vibrations become sufficiently great? May not heat, light, and actinism be but variations of one force?

There is also the consideration that in travelling through the air for many miles the amount of heat in the sun's rays may be supposed to be diminished by the amount of absorption effected by the atmosphere.

Air is usually supposed to be transparent, but has been shown by Professor Tyndall not to be entirely diathermic. From this it follows that the rays of the sun do not reach us in exactly the same state in which they leave the sun. We know something of the condition in which they come to us, but we can only infer, by reasoning as it were backwards, as to their exact nature when they set out on their long but rapid journey.

The thought might easily occur whether a ray from the sun left it in a much more homogeneous state than it reaches us, and that different effects of the passage upon different portions of it produced the various results of heat, light, and actinism. But very much more than is at present known is required to give such a theory any claim to much consideration. Still, that heat and light are closely connected together is undeniable, and it seems a fair subject of inquiry whether at least they are not two phases of the same force.

But the sun is not the only source of light. As I have mentioned, any solid substances when heated beyond certain temperatures become luminous; and if a solid be placed in a heated gas it becomes luminous, most probably from being raised in temperature by the heat of the gas.

From electricity also we get light, but even here it is only, as before, light developed from heat. For with the same amount of electricity, I can, by the same arrangement, develop either heat or light at pleasure. Thus I arrange a voltaic circuit in which the current is carried through the wire without any development of either light or heat. I separate the wires and connect them again either by a thinner wire or by a wire of less conducting power. In either case I find that the interposed wire is warm, and that by substituting either a still thinner wire or a still worse conductor, I may obtain light as well as heat, for the wire will become luminous by means of the resistance offered to the passage of the current. Therefore we may fairly say, that not only is light developed from heat, but that both may be developed from electricity.

I have elsewhere spoken of the physical forces as being naturally divided into two groups, thus:—

Heat.	Electricity.
Light.	Galvanism.
Actinism.	Magnetism.

I have also suggested that each group of three probably presents but different phases of one force, and also that possibly one of the most important differences between these two groups is that the vibrations are in one case in straight lines, while in the other they are circular or spiral. But the evident connection between heat and electricity suggests the still more comprehensive idea that all the six forces are but parts of a whole divided into two groups by some general characteristic being developed in one way in one set, and in another in the second.

(6.) **Nature of Light.**—One theory, long held in respect, was, that light was an actual emission of particles of matter from the source of light given off in straight lines: and the reflection and radiation of light somewhat supported this theory, for they obey the same laws as would be observed by actual particles of matter in motion. Refraction and absorption, however, seemed to require

some other theory, as did the fact that upon the theory of emission the eye must be constantly struck by these particles, and it is difficult to imagine that an organ so tender as the eye could bear the continued impact of atoms, however small, driven against it with such inconceivable velocity as that of light, when such acute pain is inflicted by a grain of dust blown across the road by the lightest wind.

On the other hand it was urged against the undulatory or vibration theory that as the atmosphere extended but some few miles above the earth, there was no medium of vibration between the sun and the earth, and that a vacuum of so many millions of miles could only be crossed by actual matter. Also that sound, which is admitted to be a vibration of air, could not traverse even a vacuum of a few feet, whereas light traverses with the same readiness a dense or rare atmosphere, or the most complete vacuum art can produce.

To this, in reply, it is advanced that precisely the same objections might be adduced in the case of heat which comes from the sun, which crosses the most complete vacuum, and which is yet proved with almost mathematical certainty to be a vibration. Further, to explain as well as to reply, the theory is advanced of an ether or atmosphere infinitely more rare and subtle than air, which is supposed to fill all the space in the orbit of the earth round the sun, or at least to travel with the earth, filling the interval of space between the sun and earth, and to be so aerial in its nature as to penetrate the interstices of every kind of matter.

Light and heat are asserted to be vibrations, not of the grosser atmosphere, but of this far subtler medium, and no vacuum of this can be obtained, since it is supposed to enter through the densest solids; so that the most solid machinery that could be constructed to pump it out would simply move in it, and the effect would be somewhat the same as trying to pump up water with a sieve, or to fill a bottomless tub.

If there be such a medium, it is useless, therefore, to urge as an argument that heat and light pass through vacua, because, with reference to so subtle a vapour, no vacuum can possibly exist.

We are from our very infancy intimately familiar with light and heat, and as we get older we get thoroughly familiarised with the results, rather than the facts, of electricity, especially in the case of electric telegraphy. We are told, on authority that we cannot doubt, that light comes from the sun in a few moments, and that it traverses in this time very many millions of miles of space. We know of many facts, in our own everyday observation, that concur with these statements, and we know of none to contradict them. We are therefore driven to believe them, and whatever follows from them.

Taking as bases of calculation these facts, and supplementing them by experiments, philosophers have arrived at the conclusions

already mentioned, that light is a vibration of an extremely subtle medium or gas, and that to produce the sensation of light this medium has to vibrate with a rapidity altogether inconceivable. The numbers given altogether fail to give us any specific idea as to the velocity they represent.

In an inch of space, the vapour, or medium (so called, because it rather connects the parts of the universe than has, to our gross perceptions, an individual existence), is said to vibrate some 50,000 times, each vibration being about $\frac{1}{50000}$ of an inch in extent; and this vibration is considered to pass onward at the rate of some 192,000 miles per second, making each second some 500 or 700 *billions* of vibrations. That these numbers are past our conception is no argument against their truth. If we were asked to believe that such vibrations existed, but had no practical evidence of their existence, even then we should have no right to reject the conclusion if the evidence were trustworthy; but in this case we are infinitely more familiar with the facts than with the explanation of them.

But, again, between these two theories—one that light is an actual emission of matter, and the other that it is the vibration of an ether so subtle that it penetrates and fills all interstices of all matter—a third theory is advanced, that though such an ether may well be supposed to extend from the confines of our atmosphere to the sun so as to convey light from the sun to our globe, such ether does not descend below this limit, the light being, as it were, carried on by the vibration of ordinary matter, either solid, liquid, or gaseous; so that the ether is only admitted as a means of connecting the sun and the earth. In behalf of this limited theory it is urged that just as sound, heat, electricity, can be conveyed by ordinary substances, such as air, metals, &c., so may light, whose velocity is not so great as that of electricity; and that the idea of an ether so near to us, yet giving no signs of its existence except by one set of effects (viz., those of light), and being quite free from the influence of ordinary physical laws, such as gravitation, is opposed to the spirit of physical laws in general. Also that the variations in reflection and refraction are opposed to the idea of there being but one medium of light, as such variations require that the ether should have different properties at different times or in different places.

Without pretending to decide as to which of these theories had the preponderance of evidence, one might suggest, with reference to these last objections, a few points that have not perhaps received full attention.

1. It is quite true that sound and electricity are conveyed by the vibration of ordinary substances, but neither can be, so far as is known, conveyed across an absolute vacuum (using the term without any reference to the existence of an ether), though heat and light are. Therefore there is, *prima facie*, a difference between the vibrations of heat and light and those of electricity and

sound. If there be such an ether as is suggested, it would seem that it is capable of serving as a medium for light and heat, but not for sound and electricity.

2. The assertion that this ether is imponderable (for that is the chief objection taken), might be met by the suggestion that it is difficult to imagine how it may be weighed. If it enter into every substance, and fill up every vacant space, it is difficult to see how it could sensibly affect the weight of any body into which it entered. First, because of its extreme levity; for if a room full of hydrogen would weigh but a pound or so, what additional weight could such subtle matter as we are supposing to exist add to any ordinary body, however large? Secondly, Is it possible to ascertain the weight of any substance free from this ether when there are no means of separating them? Lastly, Is it possible to weigh such a subtle, even if ponderable, ether, unless it be also possible to weigh water at the bottom of the ocean by filling muslin bags with it and weighing it with scales and weights of sponge?

3. That the ether must have properties differing with time and place, because of the different refractions and reflections of light, is scarcely an argument against the existence of such an ether on the face of the globe as well as above the atmosphere, because, supposing even that light was a vibration of this ether only, and not of ordinary matter as well, the variations of reflection and refraction might well be supposed to depend upon the quantity of the medium present, which would vary with the density of the body. The ether is not supposed to replace or enter matter, but only to fill up the intervals of space between its atoms, interstices too small for even air to enter.

The present theory therefore may be taken to be, that such an ether as has been described does exist, and acts as a medium of connection between the sun and the earth, so that the two are materially connected, though the connection be of the thinnest and rarest nature possible.

So far as we know, the only use this ether has is that of enabling heat and light to reach us from the sun. Whether it extends downwards through the atmosphere, and is the medium of heat and light even to our senses, may be considered as not satisfactorily proved, and the existence of the ether itself is inferential rather than demonstrable.

There is, however, one great distinction between the theory of an ether as the medium of heat and light, and that older theory that heat and light themselves are such ethers. In the one case the theory has been proved insupportable, and the theory of emission for these forces may be considered as of the past. In the other case heat is proved to be a vibration, and light is all but proved to be likewise. This being so, a vibration implies a vibratory substance, and the supposition of such an ether is that of a body which possesses the properties required by the facts of the *reception of* heat and light from the sun and no others.

But the thought will doubtless occur to any reader of realistic mind, Is not the idea of an ether which possesses just those properties that are apparently required, and only those, almost an absurdity? We have, it might be said, a set of results and a set of causes; we do know that one comes from the other, but we do not quite know how. We can trace part of the way, but only part, and we fill up the gap by assuming that a substance exists possessing all the properties and doing all the work required by our theories, but giving no other sign whatever of its existence. Can we, it might reasonably be asked, point to any known substance existing only for one specific purpose, as we suppose the ether to exist only to enable light and heat to move from place to place, and substance that we can neither see, hear, feel, taste, smell, weigh, nor measure? Is not this necessity for an ether almost sufficient to suggest grave doubts as to the truth of our theory, or at least the importance of reconsidering it with great care?

I can well imagine my realistic reader further asking if there be any real necessity for supposing the existence of an ether at all? You do not, he might say, demand any such medium for the passage of electricity, which is a force as delicate in its nature, as rapid in its movements, as much requiring a continuous medium, as light itself. Also heat can be developed from electricity, as electricity from heat. But, it might be replied, heat and light have to pass from the sun to the earth across a vast vacuum, and though heat can be developed from electricity, so can electricity from heat, and that it is more than probable that heat is the original form of electric force, and that the heat developed from electricity is rather a resumption of original state than a development; and further, it is also more than probable that all heat has originally come from the sun, and this theory is sometimes extended to saying that all force on the earth of every kind, excepting perhaps the tides, has originated in the sun's action upon the earth.

So that the necessity for the ether seems to be the necessity of accounting for the passage of heat and light across the vacuum between the sun and the earth; and it should be remembered that the ether is supposed to exist because of the necessity for it, not because of any proofs of its existence. It is necessary to account for the transfer of heat and light across a vacuum, and therefore it is inferred that there exists a very attenuated air, that can transfer the motions called heat and light, but which has no appreciable existence otherwise. The question may further be urged, What proofs or evidences are there of the existence of a vacuum between the sun and the earth? Why may not the air extend from the earth to the sun? It is known to become rarer and rarer as we rise above the surface, why may not the atmosphere continue, without break, up to the sun, only in a rarified condition? In fact, why may not the air itself, in a very rarified condition, be itself the *required* ether? What are the arguments

adduced to support the theory that the atmosphere extends only some forty or fifty miles from the earth's surface?

But this question implies a much larger one. Granted that the atmosphere might extend from the earth to the sun, will that account for the reception of light from the fixed stars, the distances of which are so inconceivably great? If, however, we can contrive to extend our atmosphere through the few millions of miles between us and the sun, we may not altogether despair even of the infinitely greater task of filling space itself.

Putting on one side the natural impression that the atmosphere, being composed of gases, would obey the usual law of gaseous diffusion, and so fill whatever space it has access to, what shall we put on the other side to explain why it should not do so, and why the usual limit of forty-five miles should be assigned to it?

First, the earth is not stationary, but revolves round the sun at an immense distance and with great rapidity, so that either the whole orbit of the earth must be filled with air, or else an aerial radius must revolve round the sun with the earth. The former is of the two the more rational supposition, so that the idea of our atmosphere reaching to the sun has to be extended to that of the whole orbit of the earth, an elliptic space having a major diameter of 200 millions of miles, being filled with air.

This is not inconceivable; let us assume it, and consider what follows from the assumption.

The earth, and the planets between the earth and the sun, are moving, therefore, in an aerial substance, and each will collect round itself, by its attractive force, an atmosphere of this medium, which may be supposed either to revolve with it and accompany it in its passage round the sun, or to be continually left behind and renewed. In either case, the lower strata of this atmosphere will be heavier than the upper, and denser—that is, the attractive force will have less effect as the distance from the earth increases.

Each planet may also be expected to have such an atmosphere, and some are known to be accompanied by aerial envelopes, but no trace of such atmosphere had been observed in the case of the planet Jupiter; and it was a difficulty to have to suppose a planet moving through this assumed medium and yet not collecting such an atmosphere. Also it would be expected that the progress of the planets would be impeded by the continual presence of a gas, however rarified; yet no such gradual diminution of their velocity is observable. Nor are the comets delayed, as might be expected if they passed through a resisting medium, since the calculations of their progress are made on the supposition that they move in empty space. Jupiter is now supposed to have a *very dense* atmosphere.

It is sometimes said that the attractive power of the earth has no force beyond 26,000 miles at most to overcome the centrifugal force that prevents the whole of the atmosphere from being

brought to the surface of the earth; and this is given as a reason why, whatever may be the limits of the atmosphere, it cannot be *more than* 26,000 miles. This may be quite true, but it is not necessary that the *atmosphere* of the earth should be the medium between it and the sun. It is not needed that the attraction of the earth should be exerted on every particle of air between here and the sun, but that the air, or something else, should extend throughout that space.

It is also pointed out that if the atmosphere decreases in density regularly throughout, as we know it does in the lower stratum (where the temperature falls 1° for every 200 yards, in round numbers), that at the distance of 26 miles it would be so attenuated as to be incapable of further rarefaction. But it is not absolutely necessary to suppose that the rarefaction should proceed beyond that stage, except for the difficulty that, with a medium of this kind filling up the whole of the solar system, the planets ought to have their progress retarded.

I hope to have space to return to this subject in a future chapter.

(7.) **Transference of Light.**—If I place a lighted candle in the middle of a room, light radiates from it in all directions in right lines. Every point in the floor, walls, and ceiling is lit up, supposing no solid body to be interposed. The amount of light falling on each part depends on its distance from the candle. The smaller the room the brighter the walls and ceiling seem, because the larger the rooms the larger the walls, and the greater the surface to be covered by the same amount of light.

Supposing I have two cubical rooms, one ten feet long and the other twenty, and that I place a light in the centre of each, the two lights being of equal power, then exactly the same amount of light will fall upon each wall, though one will be so much larger than the other. Thus the wall of one room will be ten feet by ten feet—*i.e.*, one hundred square feet; while the other will be twenty feet by twenty feet—*i.e.*, four hundred square feet. So that exactly the same amount of light will cover one hundred square feet, and four times as much, but in one case each square foot of space will have four times as much light in it as in the other. *Intensity* of light, therefore, really means *quantity* of light.

This may be shown another way. I place a screen one foot from a candle or gas light, with a hole six inches square opposite the light. I place also another screen two feet from the light—*i.e.*, one foot behind the other screen. The light that falls on the first screen illuminates it, and the shadow of the first screen is thrown upon the second. And the light that falls on where the first screen has been cut away will pass through and fall on the second screen. But the light passing through the hole six inches square will illuminate the second screen, and show a bright place

one foot square—*i.e.*, four times as large as the hole, though it will be lit up with only one-fourth the intensity. If now I move the second screen towards the first—*i.e.*, towards the light—the bright part will grow smaller in size, but brighter, until, when the two screens are close together, they will both be illuminated with the same degree of brightness, and the bright part of the second screen will be no larger than the hole in the first.

(8.) **Radiation of Light.**—Light, therefore, as we may infer from these experiments, travels in straight lines in every direction around its source, decreasing in brightness, but only because the same quantity of light has to cover a larger surface. If now I place a light on a hill, so that nothing stands in its way, how far will it give light? Looking at it I see the bright light and all around to be darkness. I cannot see the light passing off in straight lines—*i.e.*, light itself is not visible. But wherever I place myself I see the light itself on looking towards it—*i.e.*, the invisible rays of light are passing off in every direction, so that wherever my eye is there some vibrations enter it and make therein the image of the light. It may be miles off, yet an invisible radiation, miles in length, gives a faithful portrait of its source. The distance at which the light is visible depends on how far the light, falling on the space of a human eye, will be sufficient to excite the optic nerve. Some lights are visible forty or fifty miles.

(9.) **Reflection of Light.**—If, however, there be a post, a gate, a tree, any object, so placed that the light can fall upon it, that also becomes visible, or at least so much of it as the light falls on; but with this important difference, that whereas the light is visible from any point, the post or tree is only visible from some few points, depending on the relative positions of the light and post. The light itself is visible from *radiated* light, being itself the source of illumination, but the post is visible from *reflected* light—*i.e.*, only from light falling on it and passing off again, with its direction changed, just as a ball struck against the post would do. So that this reflected light does not pass off in all directions, but only in one, dependent upon the directions of the ray falling on the post. It may be stated as the fundamental law of reflected light, that the reflected ray depends for its direction upon the incident ray.

This dependence may be expressed thus: if light fall perpendicularly upon a reflecting surface, it is reflected (*i.e.*, bent back) in the same line, returning to the starting-point; if it fall to the right or left of this line it is reflected to the left or right, the line of reflection being *exactly* as much on one side of the perpendicular as the line of incidence is on the other.

Technically, this is expressed by saying *the angle of reflection equals the angle of incidence.*

The manner in which we get the light of the sun and of the moon will illustrate the reflection of light. The sun is a source of light, and it seems to us always the same; but the moon is as the post spoken of just now, only visible by means of the light received from the sun and reflected to our eyes. We see, therefore, only so much of the moon as receives light from the sun, and reflects it to the part of the earth where we are. It is important to bear in mind that a reflecting substance does not increase the light, or do anything except alter its direction. *a o* is the sunlight, *o* the moon, *b* the observer.

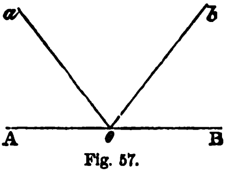


Fig. 57.

Just as we conduct water through pipes, so we can conduct light in any direction we wish. But in carrying water we convey a real substance—there is an actual transfer of matter; whereas if light be a vibration, we conduct not matter but motion when we use mirrors to guide light in any given direction. Just so when we strike a carpet hanging on a line with a stick. The vibration travels from the place where we strike it to the edges of the carpet, and there is a transfer of motion but not of matter, the carpet itself remaining in its original place.

We frequently see the sun and moon at the same time, just as we might see both the light and the post above mentioned. Really this means that we see the sun twice—once by the light directly radiated from it to our eye; secondly, by the light received from it by the moon, and thence deflected so as to fall on our eyes. But we get from this second ray the idea, not of the sun, but of the moon, and so we say that we see the moon, not the sun. For we get, in the example of the post, not all the light falling upon it, but only that much that is reflected in the direction of our eyes. Some is, as it were, lost by being *scattered*, by being re-reflected from the projections of the post. For we must remember that light will be deflected by projections of which we are scarcely conscious. The laws of natural phenomena know nothing of *nearly straight*, *nearly smooth*, or suchlike approximations; and we know that perfect straightness or perfect smoothness are almost unattainable even by the utmost care. Light falling upon any ordinary post will therefore be partly *scattered* (this is the technical term for light being *re-reflected* by numerous small projections, and so divided into many directions) and but partly reflected, the light so reflected giving the image of the post rather than of the original source of light; and in this way we say that we see both the light and the post, and not that we see the light twice.

If, however, a mirror be suspended on the post, or if the post be made so smooth as to act as a mirror, then very nearly the whole of the light falling on it will be reflected, and we shall see, not the post or the *mirror*, but an image of the light—i.e., we

shall really see the light a second time. So that the only difference between seeing a second image of the source of light, and seeing the object the light falls upon, is the degree of smoothness possessed by the object.

Generally, therefore, we may say that light falling on a very rough object is nearly all scattered and but little reflected; falling upon a very smooth object, it is nearly all reflected and but little scattered. Between these two limits we have all degrees of smoothness, the reflected image of the source of light gradually fading as the roughness of the surface increases, until it is altogether lost. But before this point is reached the image of the reflecting surface will itself begin to appear, so that we frequently see both the reflected image of the source of light, and also that of the object whose surface reflects it.

I have compared the reflection of light to the bounding off of a ball thrown against a wall, and if we bear in mind the distinction between transfer of matter and transfer of motion, the movements of a ball so thrown will illustrate very clearly the transference of light, not only when reflected, but in other cases.

If the wall be soft, the ball when thrown against it will, instead of bounding off, pass through. So, with some substances, light, instead of being wholly reflected, passes through. This is why we are able to see through glass, water, spar, and some other substances, which, from this property, we describe as *transparent*. But some of the light is reflected even when most is *transmitted*—*i.e.*, passes through—as may be seen of an evening when looking at a window you can see the light of outer objects transmitted to your eye within, and at the same time, in the pane of glass, you will also see the reflection of the fire within the room, which is partly reflected and partly transmitted, so that at the same time, by means of the same ray of light, it is visible both within and without the room.

If the light fall perpendicularly upon a transparent body, it continues in the same line; but if it fall obliquely, its direction is changed. A ray of light falling upon glass, and making an angle of 30° with another ray falling on it perpendicularly, would not continue in the same line through the glass, but would be deflected at the moment of entering, and then continue in a straight line, but in one nearer to the unaltered perpendicular line, so that the angle between them would be less than 30°. That is, the light, on passing from the rare medium air to the denser medium glass, would meet, as it were, with an opposing force, and be turned from its path, somewhat in the same way as a boat rowed apparently directly across a river arrives at a lower point than the one from which it started on the opposite side, owing to the force of the tide.

But on passing from the glass to the air on the other side, after having passed through the glass, the ray of light will be again

diverted, or rather restored, to a direction parallel to the original one, at a greater or less distance from it, according to the thickness of the glass. This, however, assumes that the two sides of the glass are parallel.

So that while light, passing obliquely from a lighter to a denser medium, has its direction changed to one nearer the perpendicular to the entered surface, in the same manner, when passing from a denser to a rarer medium, as from glass to water, from water to air, a corresponding change takes place, the light passing to a direction farther from the perpendicular to the surface.

If two straight lines are put end to end so as to make one straight line, the angle on each side is 180°—*i.e.*, two right angles. Light passes through any uniform medium in a straight line. If two media—say water and air—are traversed by a ray of light, the two straight lines will not make with each other 180° on each side, but a greater angle on one side and a less on the other, the lesser angle being always on the side towards the denser medium, and the greater angle on the side towards the rarer.

A ray of light passes through air in the line A A′, making a small spot of light on a screen at A′. I now interpose a plate of glass, or any other transparent substance, o o′ in its path. The spot of light is moved from A′ to B. Why? and how? The ray of light A falls on the glass at o and is *refracted* in the line o o′. But on passing from the glass again into the air a second refraction takes place in the direction o′ B. So that the interposition of a stratum of greater density than the air has the effect of causing a double refraction, or deflection; the resultant being parallel to the original direction.

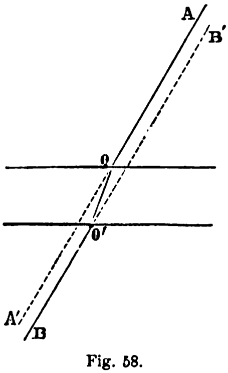


Fig. 58.

This is called *refraction*, but it will be seen that it only differs from what is ordinarily called *reflection*, in that the ray continues its course through the glass instead of returning through the air.

(10.) **Total Reflection of Light.**—I send a ray of light through air into water, its direction through the air being very nearly parallel to the line of junction; it is bent, with a less angle towards the water, and enters it.

I now move the source of light so that it falls upon the same point in the common surface, but reaches it through the water. I do this by moving the light just past the line of junction, so that the light passes very nearly along this line. On reaching the

point where it might be expected to pass out into the air, it is refracted so much that the angle it makes brings the line again within the water, and it does not pass into the air at all.

This angle is called the angle of *total reflection*, since the light is wholly reflected, and is practically not at all refracted.

Thus I hold before a window, just above the level of my eye, a glass of clear water, and look at it. Water being transparent, I may reasonably expect to see the sky through the water in the glass. But the water will seem to be covered with a bright silver crust, as though mercury had been poured on and floated on the water. Why can I not see through the top of the water, as I can through it from side to side? Because all the light, entering at the side, and passing through the water to the top, is reflected, and passes out again below, and thus gives to the top of the water the appearance of a mirror.

If *a b c* be the top of the water in an ordinary tumbler, held up before a window, all the rays of light between *m* and *o* will be reflected to the eye. The ray *o* is reflected at *c*, the ray *n* at *b*, the ray *m* at *a*. Other rays between *m* and *o* are reflected at points between *a* and *c*, all converging on the retina of the eye. All rays outside of *m* and *o* are reflected from points outside of *a* and *c*, and do not enter the eye.

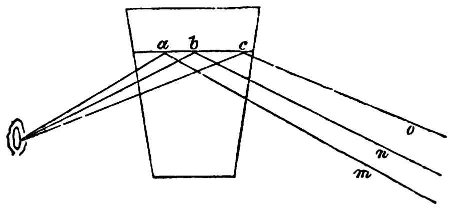


Fig. 59.

This seems at first remarkable, but we are not surprised when light, passing through air and falling on the surface of water, is reflected back into the air again. If we can once fairly grasp the fact that *light, on passing from any one medium to any other, is more or less reflected* (the amount depending upon the respective densities), there will be no difficulty in the way of our comprehending the facts of reflection, refraction, and total reflection, which (however much they may appear distinct) are but varying phases of one phenomenon.

I have discussed the **law of total reflection** in the chapter on Reflection.

(11.) **Colour.—Decomposition of Light.**—If I look at any object through a coloured glass, whatever may be its natural colour, it appears to have that of the glass. Thus all things seen through a red glass are red; through a blue glass, blue, &c. We see things only by means of the light coming from them to our eyes. If this light be coloured, the colour seems as if it belonged to the object seen by means of it.

If a ray of light falls from a candle on a mirror, and is reflected to my eye, I have the impression that the candle is behind the mirror—*i.e.*, the change in the direction of the ray of light conveys to my mind a false impression as to the position of its source. So the light from any object, if it be affected by passing through a coloured medium, conveys to my mind a false impression as to the colour of the object whence it proceeds. Nothing has really any colour of its own; colour is not a quality of any object whatever, but of the light that makes it visible.

As already mentioned (p. 97), white light—*i.e.*, ordinary light—when it passes through a prism, is decomposed, and each constituent ray of light is separated from the others. These give visible evidence of their diversity as to colour if allowed to fall on a white screen. If now I put near this spectrum pieces of coloured paper, the same in size and colour as the portions of the spectrum, and allow ordinary light to fall on them, I get two spectra side by side, and to all appearance alike. But there is this important difference: the variety of colour in one case is in the light that falls on the screen, and in the other it is on the screen itself; but the result to the eye is exactly the same. The upper portion of each spectrum is violet, and the lowest red, for precisely the same reason. In each case the violet or the red rays are the only ones that reach the eye. But the means by which this separation is effected differs in the two cases. In the one, the prism separates *one ray* into its constituent rays, and all these constituent rays become individually visible when reflected from the screen. In the other, white light falls upon the coloured papers, and is partially absorbed, partially reflected. Only the reflected light comes to the eye, and it is by this light only that the papers are visible; so that it is because each piece of coloured paper reflects a different ray that it seems to have a different colour.

Thus I can produce the appearance in fig. 60 by either of two methods. First, by placing a series of pieces of paper coloured respectively as in the spectrum, and letting ordinary light fall on them. Each piece of paper decomposes the light, reflecting, one the violet, another the indigo, a third the blue rays, &c., absorbing all the others.

V	Violet.
I	Indigo.
B	Blue.
G	Green.
Y	Yellow.
O	Orange.
R	Red.

Fig. 60.

Secondly, by passing one ray of light through a prism and obtaining a spectrum, in which all the colours of the one ray are reflected. But there is this very important distinction between the results of the two methods: the pieces of coloured paper are distinct from each other, separated by clearly discernible lines of demarcation; the colours of the spectrum blend into each other imperceptibly, so that I cannot tell where one ends and another begins. The lower rays of the red are very dark, they gradually brighten, become orange-red, red-orange, and finally distinctly orange: these in their turn pass through the gradations of orange, orange-

yellow, into yellow; these become green-yellow, yellow-green, and green; and so each colour emerges gradually from the one below it, and passes, by indistinct stages, into the one above.

This is what really constitutes colour. The cover on my table is partly black, partly red. The same light falls on all parts of it, but does not produce the same effect. The light falling on the black part is absorbed, and but little if any reflected. No light (or but very little) reaches my eyes from this part of the cloth, and it is really *invisible to me*. This is what is meant by saying that a thing is black; we mean that no light is reflected from its surface, that we do not really see it. The light falling on the red part of the cloth is decomposed, and the red rays only reflected, the other being absorbed. Therefore the cloth is said to be red.

I have spoken here of light being partially absorbed and partially reflected, using ordinary language, as though light were a real substance. But it must be borne in mind that it is but a vibration of matter, not matter itself. What, then, do I mean by a vibration being partially absorbed and partially reflected? A ray of white light falls on a piece of white paper—*i.e.*, a vibration falls on the paper of such a kind that if my eye were there instead of the paper, the impression made on the optic nerve would be that which we call white light. The paper reflects this light unaltered (or it would not be *white* paper), and I still get the notion of white light when the light falls on my eye—that is, the vibration is reflected unchanged in its rate and extent. But how can a vibration be reflected? Only by another vibration being set up. The vibration reaches the surface of the paper in the direction *a o*, and by its "reflection" is meant that another vibration is set up in the direction *o b*—that is, the result is in every way the same as if the vibration had not met with the paper or with any other object, excepting that it has its direction changed. This is all the white paper does for the ray of light falling on it.

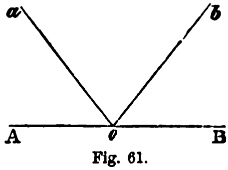


Fig. 61.

But now I substitute a piece of coloured paper for the white piece. The same ray falls on it, is reflected in exactly the same direction, and produces the same effect on my eye in all respects except one. That is, the paper, instead of being white, is blue, or red, or green, as the case may be. Let it be red. What is the difference in the two cases? Just the difference between white light and red light. In the one case, the paper reflects all the light—*i.e.*, sets up another vibration of the same kind as the one falling on it; in the other, the vibration set up is not the same. I have said (p. 97) that white light may be considered as a compound vibration, made up of a number of vibrations, differing

in rates and extents. According to one theory there are seven of these, each one giving to the eye a different impression—one violet, another indigo, another blue, another green, another yellow, another orange, the last red. These, as we have seen, are separated by a prism. The piece of red paper also separates them, and absorbs all but the red ray—*i.e.*, all the other vibrations are destroyed, while the red one alone is continued. The red paper sets up only one vibration out of all that fall on it; this we call reflection. It destroys all the others; this we call absorption.

If the paper be green, then all but the green ray are absorbed; if yellow, all but the yellow ray, &c. But Sir David Brewster's theory, that there are but three primary colours—red, yellow, and blue—requires a modification of this statement. For if this be true, and all colour but these three be compounded of these, then such as orange, indigo, violet, are not made of single elementary vibrations, but are compound, though in a less degree than white; that is, these are derivative colours, just as are pink, mauve, and lilac.

(12.) **Spectrum of Colours.**—But there is still another phase of this subject. The language used in describing the directions and effects of these vibrations usually conveys the notion of matter rather than of motion; and it is almost impossible to prevent this except by the most tedious repetition. When I speak of white light being a compound vibration, made up of other vibrations, it is necessary to realise fully that each of these may be modified by increase of rapidity or extent. So that it is possible to conceive that all light, of whatever colour or shade, may be but one vibration, and that all varieties of colour and shade may be caused by modifications of the velocity and extent of this vibration.

Thus white light—*i.e.*, ordinary light—falls on a prism, and on the other side is given off a spectrum, made up of a strip of light of which the colour is constantly changing. From red at one end to violet at the other, it passes through the gradations of orange, yellow, green, blue, and indigo, not changing suddenly from one to the other, but shading imperceptibly, so that it is impossible to say where one ends and the other begins.

I have given elsewhere the figures expressing generally the number of vibrations in a second, the number of waves in an inch, and the length of the waves, made by an ordinary ray of light. But these figures vary very much as we go up or down the spectrum. The red rays vibrate with the least rapidity, make longer waves, but fewer of them. The violet, at the other extremity, vibrates the most rapidly, makes the most waves, but has the smallest extent of wave-length. The intermediate colours are between the red and violet in all these points. Speaking *in round numbers*, we may give the following table:—

Colour.	No. of waves in a second, in billions.	No. of waves in an inch, in thousands.	Length of the waves, in ten-millionths of an inch.
Violet, . . .	700	57	175
Indigo, . . .	650	54	185
Blue, . . .	625	51	195
Green, . . .	575	47	210
Yellow, . . .	550	44	225
Orange, . . .	500	41	240
Red, ...	475	39	255

I have expressed the above with as few figures as possible, in order to show as clearly as I can the relations between them. For this purpose I have omitted all the noughts before or after the significant numerals, expressing 700,000,000,000,000 as 700 billions, and .0000175 as 175 ten-millionths. But it is important not to be misled by this. To understand the comparison of the number of vibrations still more clearly, I will express them in yet smaller numbers.

Violet,	7
Indigo,	$6\frac{1}{2}$
Blue,	$6\frac{1}{4}$
Green,	$5\frac{3}{4}$
Yellow,	$5\frac{1}{2}$
Orange,	5
Red,	$4\frac{3}{4}$

These numbers give roughly the number of waves in a second of time expressed in *hundreds of billions.* From these small numbers we see better than from the larger ones, that while a red ray vibrates $4\frac{3}{4}$ times, an orange ray vibrates 5 times. This means that when a ray of light vibrates 475 billions of times in a second, the impression it makes on the optic nerve is that of red light; but that if by any means it can be made to vibrate more rapidly, the colour—*i.e.*, the impression on the optic nerve—changes gradually from red to orange; and when the number of vibrations reaches 500 billions, it ceases to be red, and becomes orange.

If the number of vibrations be still increased, the same ray of light will gradually change from orange to yellow, then from yellow to green, from green to blue, from blue to indigo, from indigo to violet, and finally, according to some theories, it becomes lavender.

I say that the *same ray of light*, as it vibrates more rapidly, makes a different impression on the eye; but it will be at once objected that since *the vibration itself is the light*, if the vibration be changed, the light must be changed—*i.e.*, it is no longer the same vibration, and therefore no longer the same ray of light. And this is quite true. And it may be asked, How can a vibration be changed in its rate? But I have, I hope, made it clear that the colour of any object depends upon the rapidity of the vibrations. Thus when I put before me a piece of red blotting-paper and a blue book, the reason that one is red and the other

blue is that the vibration from one is at the rate of 470 billions per second, and from the other at the rate of 625 billions. For the same reason a violet dress is violet because the light from it vibrates at the rate of 700 billions per second.

The question cannot but arise, Whence this variety of speed? Why does light vibrate at different rates accordingly as it comes from different substances? But the answer is not so easy to give. One feels tempted to reply to it by another, asking, Why should it vibrate at all? I admit a ray of light into a small chamber otherwise dark, on the side of which I have placed several wafers of various colours. Until the light be admitted the wafers are alike—they have no colour at all. The same light falling on them produces different effects. The light coming from the red wafer vibrates at the rate of 475 billions of vibrations per second. Clearly the cause of this special rate of vibration is in the wafer itself. So a blue wafer sets the light falling on it in vibration at the rate of 625 millions of vibrations per second. Therefore the blue wafer differs from the red wafer in some manner very important as respects its action on light. This would seem to be in the colouring matter. Just as red and blue glass produce different effects on light, not because of any difference in the glass, but because of the staining matter contained in them. Blue glass is blue usually because it contains cobalt; and it would seem as if it were to the action of some few substances used as colouring matter that we must look for an explanation of the decomposition of light by ordinary methods—that is, for the reason of *colour* in general.

But the question will arise, Is it not possible that difference of colour arises from an increase or diminution of the velocity, or of the wave-length, of any given ray of light? Is it not easier to conceive that light is a simple vibration, and that colour is a result of some cause affecting this vibration? May not the phenomena of light and colour be explained by means of a less complex theory than the one usually put forward?

(13.) **Elements of Light.**—These questions may be summarised thus: What is the element of light? Is it one element only, and are the various colours only phases of this element Are there really primary colours; and if so, how many? Newton considered there to be seven, already mentioned. Brewster asserted that there are but three—red, yellow, and blue. Euler was of opinion that between the red and violet extremes of the spectrum there are innumerable primary vibrations. Euler's theory would make white light to consist of an infinite number of primary vibrations, each having its peculiar tint. Newton's makes it to consist of but seven such vibrations, and all other colours to be formed by combinations of these. Brewster's three primary colours are supposed to form all others. But each theory considers white light to be a compound light, and that the action of a prism is to separate this compound into its constituents. Is it

impossible that white light can be itself a primary vibration, forming one of the innumerable primaries of Euler? May not the limitation of primary rays to the spectrum be a needless one? May not white be the highest note in the optical scale, just as red is the lowest? But no spectrum gives a white ray, it may be objected. It could not reasonably be expected that it could, seeing that what is called refraction is really retardation; and if white light be considered as the highest vibration, such retardation would at once alter it.

But it might be objected that if coloured light were only white light retarded, then whenever a ray of light passing through air fell on glass or water, it should at once be changed in colour because of the retardation, whereas we know that light passing air, water, or glass remains white.

The remark is reasonable, and, I believe, true. But it must be borne in mind that it is air and not glass or water that is in immediate contact with the eye. If the light be retarded on passing from the air to the glass, it is accelerated (probably to its original velocity) on passing again into the air, so that the effect on the eye is as if no glass or water had been interposed, save that the ray is a little on one side of its original direction, but parallel to it.

Assuming for a moment that this idea is worth consideration, let us take some of the facts well known, and compare the explanations of them offered by the several theories. The actions of an ordinary prism will serve as one example. Pure white light falling on a prism passes from it as several rays, each having a different colour, owing to a different velocity, wave-length, and number of waves in a given space. The theories of Newton, Brewster, and Euler all suppose that the difficulty of passing through the prism retards the passage of the ray, and that the various rays having various velocities are retarded in various degrees, and so separated. The only difference between these theories is as to the number of primary rays so capable of separation, whether it be three, seven, or infinite.

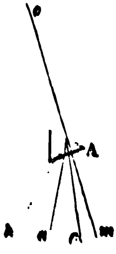


Fig. 62.

Refraction by means of a prism is usually described as commencing directly the light enters the substance of the glass, and each ray is considered to commence its divergence at once. This is usually represented thus:—

The ray on entering the prism is assumed to be at once decomposed and to pass through the prism in several rays. These all pass out at various angles with $o\ m$, the original direction, but all between that original direction and the base of the prism. In fig. 62 the lines $a\ b\ c$ are all on one side of $o\ m$. But if, instead of a prism, I interpose a plate with parallel sides, I have only a slight alteration of direction, and no breaking up of the primary into coloured rays.

The line A o becomes the line o′ B, but there is no divergence of rays from o′. Can we think that the ray on entering is broken up into divergent rays, but is again converged to the second surface? Or, can we think that the ray of light has the power of discriminating between a prism and a plate, and becomes divergent or remains intact accordingly?

It would seem, therefore, probable that in some cases, at least, the divergence does not take place until the light reaches the second face of the prism. I have discussed the matter more fully under "Refraction."

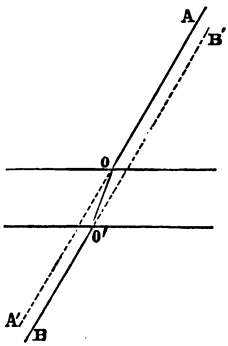


Fig. 63.

(14.) **Temperature of a Spectrum.**—I make a small wooden box, lined with black paper. To this I admit light by a small hole, in front of which I put a prism. The result is a spectrum on the opposite side of the box. After examining the colours of the spectrum, I propose to give a moment's time to its temperature, and therefore hold a thermometer in different parts of it. Speaking generally, I find that the temperature rises regularly as I pass from the violet end of the spectrum, where it is least, to the red end, where it is greatest. But this rise does not terminate with the visible spectrum, as it might be expected to do. On the contrary, it continues—that is, as I pass the thermometer away from the red end of the spectrum it continues to register an increasing temperature, as though there was an invisible continuation of the refracted rays. Fig. 64 shows this variation in the temperature.

(15.) **Chemical Power of Light.**—If now, instead of a thermometer, I place on the screen where the light falls a slip of paper that has been steeped first in a solution of common salt, and secondly in nitrate of silver, I shall have a means of testing

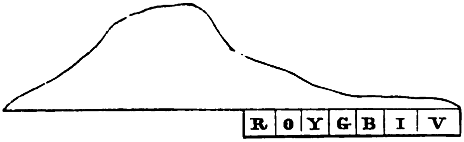


Fig. 64.

where the power is that effects the chemical changes so well known by their results. Just as my eyes tell me the colours of the parts of the spectrum, and the thermometer their relative temperature, so this strip of paper will indicate the extent of the photographic power of the sun's rays and its variations of intensity. Also, just as the thermometer reveals to our perception the existence of heat-rays beyond *one extremity* of the spectrum, so the strip of paper

displays the action of other invisible rays beyond the other extremity. The effect of solar light upon chloride of silver is to darken it, and the strip of prepared paper is in this way darkened by the spectrum, but much more so at one end than at the other. In the violet part it is much coloured, in the blue less so, in the green less so, in the yellow, orange, and red scarcely at all. Beyond the violet the darkening continues for some space, showing that there are rays above the violet as well as below the red.

Knowing that the number of vibrations increase regularly from the red end to the violet end of the spectrum, it is but reasonable to infer that the invisible rays beyond the red end vibrate at a less rate, and that the invisible rays beyond the violet end vibrate at a greater rate, than the rays of the spectrum itself. That is, the heat-rays, light-rays, and chemical rays make up altogether but one set of rays, of which only the central portion is visible, since the vibration of the heat-rays is too slow, and that of the chemical rays too fast, for our sense of vision to take cognisance. There are sounds too loud and sounds too soft for our hearing, so also are there lights too dark and lights too bright for our seeing.

A vibration at the rate of 450 billions per second gives the impression of red, at 720 billions per second it gives the impression of violet. Any rate of vibration less than 450 billions per second gives no impression of colour, and is not light, though it may be heat; any rate of vibration above 720 billions per second also gives no impression of colour, and, it would appear, is not light, though it has a power of affecting chemical compositions, which is sometimes called *actinism*.

(16.) **The Rainbow** is an example of the variety of colours produced by refraction. For its production it is essential that there should be present sunshine and rain—sunshine as a source of light, rain as a means of refraction. If spheres of glass, or any other refracting medium, could be suspended in the air, the same effect might be produced. We may imagine the falling rain to be a kind of prism which is constant as a whole, although its constituent drops are constantly passing away and being replaced. The light falling on this is refracted, and coloured rays are given off in many directions. When these are given off so as to reach the particular spot where we may be, we see them arranged much as in a spectrum. But there is this difference between a spectrum as produced by a prism and one produced by rain, that in the prismatic spectrum we have the colours produced by the decomposition of a single ray, while in a rainbow each drop of rain is a separate prism, and sends but one coloured ray. We have therefore as many prisms and decompositions as there are colours, one ray of each forming part of the spectrum that we call a rainbow.

But if the rain-drops be the means of decomposing the light and

so producing colour, it might be asked, Why does not the rainbow come down with the rain? In one sense it does; but the moment it does so it becomes invisible to me, while the fresh drops that continually succeed and fill up the place of the others perform exactly the same work as they did, and form precisely the same combination of colours. It may be greatly doubted if any two people see exactly the same rainbow, and whether, if the rain-drops did not move, the perception of one could be so general as it is. Probably the rain-drops as they move downwards continue to refract the light, and so send rays to different points.

Secondly, it may be asked, Why is a rainbow a bow at all? Why not a straight line? The answer to this is, that if the sun be fairly behind my head, though of course much above it, then, whatever be the position of a drop of rain that sends to my eye a red ray, either to the right or the left of me, the same result will be produced by a drop in an exactly corresponding position on the other side of me. And by the same reasoning it seems clear that a drop as much above me will produce still the same result. So that with the position of my eye as a centre, and the distance from it of any given drop of rain, I may describe, in imagination, a circle, every point of which, if there be there a drop of rain and the sun can fall on it, making the same angle, will send to me the same coloured light. The obstacles in the way of this complete circle being formed, and the various positions the sun may have with regard to this circle, are quite sufficient to account for its incompleteness, answering, not the question "why a rainbow is a bow," but "why it is not a circle."

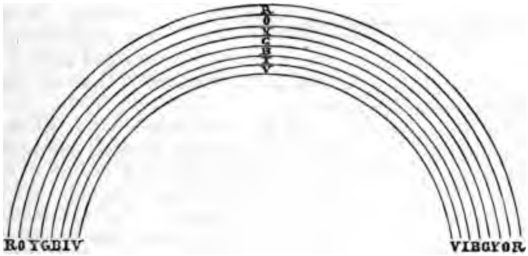


Fig. 65.

Fig. 65 shows a normal rainbow, made up of the seven colours commonly known. The half-circle of red, R, is caused by a semicircle of rain-drops, each decomposing the light falling on it, and each reflecting to the same spot, that of the observer, a red ray. In the same way the semicircle of orange, O, is caused by orange rays being reflected, the circle Y by yellow rays, and so on; each reflecting a different colour to any given spot.

(17.) **Spectrum Analysis.**—I dip the end of a glass rod first in water to moisten it, and then in any salt of sodium. Holding this in the flame of a spirit-lamp, it burns with a bright yellow flame. If I change the sodium salt for one of strontium, the flame is crimson; if for one of calcium, a light red; of barium, a yellow green. Thallium gives a bright green, potassium a violet, aluminium a blue, and copper also a green.

Any of these when raised to a vapour and heated gives out light, and this light when it passes through a prism gives a spectrum; but there is the important difference, that this spectrum is not a long strip of varied colours, but simply one or more bright stripes placed across the space that would be occupied by an ordinary spectrum if there were one. Thus the spectrum of sodium is one band of brilliant yellow, of thallium one bright green band, of lithium a bright crimson band, and a fainter one at some distance from it. The spectra of barium, calcium, and strontium have numerous bright bands.

In fig. 66 I have shown the chief *dark lines* of the solar spectrum, and the chief of the *bright bands* that constitute the spectra of sodium, barium, calcium, and strontium. The bright spaces in the engraving are very much too wide, but it is impossible to show them with any approximation to accuracy. It will be noticed that the position of the bright band in the sodium spectrum is identical with that of the dark line D of the solar spectrum.

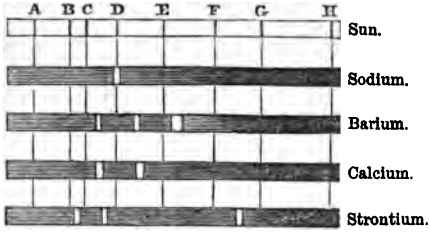


Fig. 66.

No two elements appear to give the same band, or series of bands, so that one elementary substance is at once distinguished, with unerring accuracy, from another by this means. Also, a compound substance gives as its spectrum, not one of its own making, but those of the elements composing it. If two vapours be heated together, the spectrum of one does not appear in any way to interfere with that of the other, but the two lines or sets of lines appear individually without any confusion or interference.

But if in the path of the rays so refracted I interpose vapour of the same kind as the heated vapour giving out the ray of light, the bright bands no longer appear. Sodium vapour absorbs the light given out by sodium. Hydrogen absorbs the light given out by hydrogen. Iron, raised to a vapour, absorbs the light given out by iron.

I have described (p. 98) the spectrum cast by solar light as

being crossed by a multitude of black lines, as though the light had passed a grating and been broken up into pieces. The absorption of some of the light from its passage through vapours of the same kind as those producing the light, causes these black lines. A black line in a spectrum is evidence of the presence of the same vapour both in the source of light and in its path. The position of the line in the spectrum points out also what the vapour is. A bright yellow line is indubitable evidence of the presence of sodium in a state of incandescence; a black line, instead of the bright yellow one, is as complete an evidence of the presence of sodium vapour in the path of the sodium light. This black line is found in the solar spectrum (one of the best known, called D), and is accepted as proof of the presence of sodium in the sun.

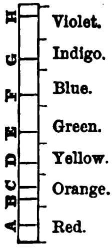


Fig. 67.

So with iron and magnesium. If I arrange my prisms so as to throw side by side the spectrum of a solar ray and the spectrum of iron or magnesium vapour, I find dark lines in the solar spectrum exactly corresponding with the bright lines in the metallic spectrum. In this latter I can convert these bright bands into dark ones by interposing a vapour of the metal giving the light. I now have two sets of dark lines exactly corresponding. One set (in the metallic spectrum) I know to be caused by the light of a particular metal (say *iron*) passing through a vapour of the same metal. I also have every reason to believe that no other substance can give the same set of lines, and therefore the black lines in the solar spectrum are conclusive evidence of the presence of iron in the sun.

In this way I am led to the belief, or I may say certainty, that there are in the sun many of the elements familiarly known to us, such as iron, sodium, magnesium, copper, zinc, barium, calcium.

This seems very simple to read, and not difficult to comprehend; but it requires delicate apparatus, dexterity of operation, careful and continued observation, and, above all, *patience* and *fidelity*. Nature does not always write in glaring colours or in letters of gigantic size; but her characters, however minute, are clear, and if difficult to decipher, are written with unerring accuracy. To understand her language we must bring to the study patience and humility, determined to read what is written, not what we imagine is or ought to be.

So in *spectrum analysis* we have to examine lines of such extreme tenuity that we require a microscope to enable us even to see them, so scattered that we cannot see them all at once, and of such a delicate character that they are invisible except in the complete absence of all other light.

(18.) **Spectrum Apparatus.**—To overcome all these difficul-

ties it has been necessary to adopt new apparatus, and the name of "*Spectroscope*" has been given to this new combination of lenses and prisms, which enables us to see these delicate lines which tell us so unerringly the very nature and composition of the heavenly bodies, and have inaugurated a new branch of science.

As an illustration of the importance and value of the spectroscope it may be mentioned that it seems to have settled the long-pending question as to the nature of nebulæ. It is found that the spectrum in this case is but a few bright lines, leading to the inference that the nebula is not a cluster of very distant stars, as has been sometimes supposed, but a mass of glowing gas. All known stars emit light of varied refrangibility, that can therefore form a spectrum; but the nebulæ emit light of one refrangibility only, and therefore only form a few bright lines in the spectroscope.

The *spectroscope* is, essentially, a telescope with a prism at one end. The prism is for the purpose of refracting the light, the telescope to magnify the image.

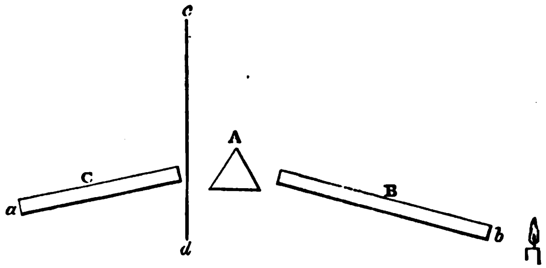


Fig. 68.

The above figure shows the simplest form of spectroscope, consisting of a prism A, having on one side a tube B, and the other a telescope C. The end *b* of the tube B is closed by a brass plate, which can be removed very gradually by a small screw. For use a very narrow slit or opening is made, and a ray of light passes down the tube either from the sun or from any substance burnt in a spirit-lamp near the opening. The light passes through the prism, being refracted according to its nature, so that it would fall upon a screen *c d* if one were placed to receive it. Instead of this, however, the telescope C is placed so as to receive the different portions of the spectrum as it is moved to the right or the left. For this purpose it is mounted on a pivot.

The instrument is used thus: I open the tube B so as to allow a narrow beam of light to enter and pass down and impinge on the prism A. I then turn the telescope C to the right or the left *until the portion* of the spectrum that I wish to examine falls on

the object-glass. The use of the telescope is then to magnify this object in the ordinary way. It will be seen that the whole of a spectrum cannot be seen at once through the telescope, any more than the whole of the stars can. To compare the lines in one spectrum with those in another the telescope is fitted with a graduated arc, so that the exact position of any line in a spectrum can be registered for reference.

(19.) **Fluorescence.**—When the light falls upon a prism, which we place in its path for the purpose of refracting it, it sends out a fanlike set of rays, but it also absorbs some of the original ray. Therefore the spectrum is really only a portion of the light that falls on the prism. Glass seems to absorb the rays of high refrangibility more than the others. Quartz does this to a less extent than glass, and therefore gives a longer spectrum, so much longer that the invisible portion—the rays beyond the violet—extend to twice the length of the coloured rays. But a spectrum has been obtained in which the invisible rays extend even further than this, even to five and six times the length of the visible portion.

These invisible rays may be made visible more or less by several means. Thus I produce an ordinary spectrum by means of a prism of quartz. Part of this is visible, part (and the larger part) invisible. I now fill a tube with sulphate of quinine and hold it in front of the spectrum, passing it along the visible rays from the red to the violet end. The colours of the spectrum are but little, if at all, affected; but when I reach the invisible part of the spectrum, I find a pale-blue colour developed, showing clearly that the spectrum extends far beyond the visible portion of it, and also that the invisible portion is so only because its number of vibrations is too great to impress our sense of vision. That this number is reduced is shown by the blue colour.

Another method of rendering these extreme rays more or less visible is to let them fall on some surface that will affect them in the same way as the quinine sulphate. Ivory and yellow glass, as well as phosphate of uranium, are such substances.

The fact that rays can have their velocity and consequent refrangibility thus changed cannot but suggest serious considerations as to whether light be really the compound of absolutely primary rays it is ordinarily considered to be.

SUMMARY.

THE **eye**, which is our only organ of sight, or means of appreciating light, is essentially the *termination* of the **optic nerve**, spread out, in a number of *very fine filaments*, over part of the inner surface of a hollow sphere, which we call the **ball of the eye**. The light falls upon these threads, and, by exciting the nerve, communicates to the brain the sensation of sight. Light radiated from any object would spread over the surface of the eye, as over any other surface, were there not the means of convergence. This convergence is necessary for the formation of an image on the **retina**, or reticulated surface formed by the nerve filaments. It is effected by means of two lenses which close in the front of the eyeball, and on which the light falls. The first, and outer, of these is the **cornea**, a cylindrical convex lens, which, by ordinary refraction, converges rays before divergent. A second lens, behind the first, and called the **crystalline lens**, increases this refraction, and (in a perfect eye) brings all rays falling on the eye to a point on the retina.

The **varieties of light** are—*sunlight, light from heated bodies, electric light*, and *phosphorescent light*. Page 94.

Light moves with a **velocity** of about 200,000 miles per second. Page 102.

Lights are compared by means of their brightness, or of the shadows which they cast. Page 103.

Light remains upon the retina during an appreciable interval of time. Page 104.

Light is a vibration, either of ordinary matter, or of a very rare and subtle ether, but probably the former. Page 105.

Light **radiates** in straight lines, and in all directions. Page 111.

Light is **reflected** in the same manner as *heat* or *sound*. Page 112.

Light is **refracted**, but refraction is only a peculiar phase of reflection. Page 115.

Total reflection is also only a peculiar phase of reflection. Page 115.

Colour is obtained only by refraction and dispersion of light. Page 116.

Coloured light differs, in its *rate of vibration*, *length of wave*, and number of vibrations, from white light. Page 120.

White light is either compounded of coloured lights, or is one of them and the highest in the scale. Page 121.

Ordinary white light, *after passing through a prism*, assumes the form of a **coloured spectrum.** Page 123.

The colours of the spectrum pass from **red,** through **orange, yellow, green, blue,** and **indigo,** to **violet.** Page 123.

The **temperature of a spectrum** increases as we pass from the violet towards the red extremity, and *continues to increase afterwards.* Page 123.

The **chemical power of a spectrum** increases from the red to the violet, and *continues to increase afterwards.* Page 123.

The **rainbow** is a special instance of *refraction* and *reflection.* Page 124.

Any substance raised to an incandescent vapour gives a *spectrum;* and each element a spectrum peculiar to itself. Page 125.

The Spectroscope is an apparatus to detect and measure these spectra. Page 127.

Invisible portions of a spectrum may sometimes be rendered visible. Page 129.

ELECTRICITY.

Frictional Electricity *Franklinic Electricity* *Static Electricity*	These three terms are all synonymous.

(1.) **Introduction.**—A piece of sealing-wax briskly rubbed with a piece of flannel has the property of attracting very light substances, such as pieces of gold-leaf, pith-balls, &c. So also has a glass rod, but the electricity developed in one case seems to be different from that produced in the other. Thus substances attracted by an excited glass rod will be repelled by an excited stick of sealing-wax, and *vice versâ*.

I strew some small pieces of gold-leaf and some pith-balls on a sheet of paper, and hold over them a stick of sealing-wax after rubbing it smartly. The pieces of leaf at once fly to the wax, and remain attached to it; while the balls will jump to the wax, adhere for a few seconds, and then fall. The pieces of leaf being lighter, remain for a much longer time adhering to the wax, though it may be noticed that the attraction gradually decreases in force.

It would seem as if the friction had developed on the surface of the wax rod some force that attracted the balls and gold-leaf, but was unable to retain them; as though, after attraction, they themselves underwent some change. Exactly the same effects are produced by means of a glass rod excited by a piece of silk; but it will be found that the two attractive forces are not identical, but are rather two parts of a more comprehensive force. If I cause a few pieces of gold-leaf to be attracted to a stick of wax, and then hold a freshly-excited rod of glass near them, they will fly from the wax to the glass; and if the wax be then again excited they may be reattracted, and so on, as though one of the force was strong when the other was weak, and *vice versâ*. But in the case of a student new to the work of experimenting, it is well to bear in mind that the results of experiments are not always so simple or

uniform as might be expected if it be not recollected that in experimental science we work in a vast factory, where the varied forces of the world are in full action around us, and often in so delicate and subtle a manner that our senses are too gross to take cognisance of them; and that to secure success an experimentalist needs accurately-finished apparatus, or, what is still more useful, a skill in manipulation that can only be acquired by practice, and a ready perception and appreciation that is the reward of long-continued and humble application.

If two slips of gold-leaf be enclosed in a small glass and connected with an external conducting substance, such as a small plate of brass, we shall have a delicate means of testing the presence and strength of electricity. If any quantity of electricity, however small, be brought to the brass plate, it will be conducted to the gold-leaf, and its presence will be evidenced by the divergence of the leaves.

Fig. 69 shows one of these "gold-leaf electroscopes," consisting of an ordinary glass shade on a wooden stand, closed at the top by a metal stopper, the upper part of which is a flat plate. The lower end has attached to it two strips of gold-leaf, fig. 70. These hang side by side until electricity is communicated to the plate at the top. This top, the rod of the stopper, and the strips of gold-leaf being all metallic, the electricity spreads over the whole. The gold-leaves are the only parts capable of motion—*i. e.*, which the electricity has force enough to move—and they are repelled accordingly, whether the electricity be positive or negative, fig. 71.

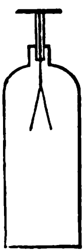


Fig. 69.


Fig. 70.

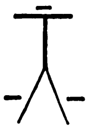


Fig. 71.

Electricity can be generated, as we have seen, by the friction of a stick of wax or of a glass rod. To convey it from the glass or wax to the electroscope (as the gold-leaves enclosed in a glass with external brass plate is called), it is convenient to use a kind of shovel or spoon, made by fastening a piece of paper covered with gold-leaf to the end of a stick of sealing-wax. The paper will wipe off, as it were, the electricity from the excited surface and convey it to anything else with which it may be brought in contact, while the wax handle prevents its escape.

If, therefore, after exciting the surface of a rod of glass or wax, I draw the paper lightly over it, and then lay it on the brass cap of the electroscope, I charge the latter, as is shown by the divergence of the leaves. I might lay the excited rod itself on the cap, but the use of a paper shovel is much better. Wax, glass, or any substance useful for the development of electricity, will be found to be a non-conductor of it; so that only the electricity generated on the actual *spot in* contact with the cap would pass

to it, while the paper, when drawn along the excited surface, cleans it of the electricity, which it conveys to the cap in a much more delicate and graceful manner.

Using this electroscope, we may compare the electricity developed by rubbing the glass rod with that produced from the stick of wax. If by means of one I cause the leaves of the electroscope to open, the other will cause them first to close and then again to diverge. Thus, if I apply resinous electricity, the leaves, being both negative, repel each other. If when they are apart I apply an excited glass rod, the leaves close, because the vitreous or positive electricity counteracts the negative and restores equilibrium. But it is nearly impossible that the two amounts of force should be exactly equal, so that the leaves are almost sure to diverge either from the remaining force of the negative, or from the surplus force of the positive. The leaves will diverge whether they be charged with positive or with negative electricity, so that their divergence tells only that they are electrified, not with which force.

The electricity of a glass rod is called **vitreous electricity**, while that of a stick of wax is called **resinous**. Also glass is said to give **positive**, and wax to give **negative**, electricity. But it is easy to develop *resinous* electricity from glass, and *vitreous* from resin, by using other rubbers than the silk and flannel ordinarily used. If I rub glass with flannel or cat's skin it is negatively electrified; if with silk or the hand it is positively excited. So I excite resin negatively with flannel or cotton, and positively with gun-cotton. Silk is usually taken for glass and flannel for resin, because, of all easily obtainable materials, these are the most efficacious. If I rub smooth glass with rough glass the smooth is excited positively and the rough negatively. So that whether the electricity be positive or negative depends upon the nature of *both* bodies. The term *vitreous* is derived from glass, and *resinous* from resin; but the terms *positive* and *negative* bring before us the theories that are used to account for the effects of the two electricities and for their differences.

One theory is that of the existence of two fluids, so subtle as to be perceptible only by their effects, that pervade all substances, and when united in equal quantities, give, as it were, electrical equilibrium, but either of which by itself evinces a powerful attraction for the other wherever it can be found.

Thus a stick of wax in its natural state is supposed to contain both fluids, but when rubbed to have but one, the other being removed by the friction. So with a stick of glass. This theory supposes that the fluid removed is to be found on the surface of the rubber; and it is always found that when a glass rod is by friction made positive the rubber is negative, and that the flannel which excites in a stick of wax negative electricity, is itself excited positively.

Assuming, therefore, the theory that all bodies contain natur-

ally these two fluids in equal quantities so as to be electrically at rest, friction removes from glass one of these, and from wax the other, the one removed being found on the rubber.

But another theory assumes the existence of but one fluid; and a body is said to be positively electrified when it contains more than its natural quantity, and to be negatively electrified when it contains less. Thus by rubbing a stick of wax with a piece of flannel, I am supposed to remove part of the natural amount of the electric fluid from the wax to the rubber, so that the wax contains less, and the rubber more, than its normal quantity. Then the wax is negative and the rubber positive.

In the same manner, if I excite a glass rod by friction with a piece of silk, the quantity of electricity in the glass is increased, and in the silk decreased, by the same quantity, and then the glass is positive and the silk negative.

Vitreous, or positive, attracts negative, or resinous, electricity, but repels its own kind. The same is true of negative electricity—*i. e.*, each kind attracts the other.

If the two-fluid theory be correct, then it is necessary to assume that the two fluids are both antagonistic and sympathetic —*i. e.*, they display opposite qualities, but yet attract and satisfy each other. This is in its favour rather than a difficulty.

But the single-fluid theory only requires that a body positively electrified (*i. e.*, containing more than its normal quantity of electricity) should attract any substance that is negatively electrified (*i. e.*, containing less than its normal quantity), to which it can impart its excess; and also that a negatively electrified body should attract any positive substance, from which it may receive what it needs. So that by this theory there is a constant tendency towards the restoration of an equilibrium that has been disturbed; and two bodies, containing each less, or each more, than the normal quantity of electricity, naturally repel each other, as tending to increase the disturbance rather than to restore the equilibrium. I do not think either theory will exist very much longer.

(2.) **Effects of Electricity:** These are numerous and varied.

(A.) *Attraction and Repulsion.*
(B.) *Development of Heat.*
(C.) *Development of Light.*
(D.) *Chemical Action.*
(E.) *Development of Magnetism.*

(A.) *Attraction and Repulsion.*—I take two glass rods, two sticks of shellac or rosin, and a few pith-balls. I rub the glass with silk, the shellac with flannel. The glass rods are now electrified positively, the shellac sticks negatively; the pith balls are neutral.

The glass rods attract the shellac and the pith-balls, but repel each other.

The shellac sticks repel each other, but attract the glass rods and the pith-balls.

The pith-balls neither attract nor repel either the glass, or the shellac, or each other.

Generalising this we may say—

All bodies that are electrified positively repel each other, but attract all other bodies, whether negatively electrified or neutral;

All bodies that are electrified negatively repel each other, but attract all other bodies, whether positively electrified or neutral.

All neutral bodies have no attractive or repulsive action at all.

When one body is attracted by another, the common stock of electricity is divided between them, according to their extent of surface. Accepting the single-fluid theory, a glass rod is positively electrified because it contains more than its proper share. It attracts any body that is negative—*i. e.*, containing less than its proper share, or neutral—*i.e.*, containing its normal amount. The negative body becomes more nearly neutral, the neutral body becomes positive, because each receives electricity from the positive body. So a negative body makes a neutral body also negative, and a positive more nearly neutral, by drawing from them part of the electricity they possess.

(B.) *Development of Heat.* — If I connect a positively charged body with one negatively charged, by means of a thick metallic rod, the electricity flows freely along it, and gives no sign of heat. But if I gradually diminish the thickness of this connecting rod, I also gradually increase the amount of heat developed. It is not that electricity *produces* heat, but that it *becomes* heat. I use a stout brass rod to transmit electricity, and it presents no sign of such conversion. I substitute a thinner rod, and it feels warm: a finer wire becomes hot. Or (instead of diminishing the thickness of the connector) I substitute one of less conducting power, and with the same result of heat. It would seem from this that electricity becomes heat when a difficulty is interposed in the way of its passage. If I sprinkle a little gunpowder on a metal plate, an electric spark passing between thick metal wires will pass so quickly and easily that the gunpowder will not be fired. But if I interpose a badly conducting substance, such as a wet string, the passage of the electricity will be impeded, part of it will become heat, and this heat will fire the powder.

If I make a hole, an inch across, in the side of a tub of water, the water will flow out at a certain rate; if I make the hole larger, it will flow more rapidly; if I make it smaller, it will flow more slowly. Just in the same way the thicker a conducting rod is, the more easily electricity will flow through it. If now,

instead of altering the size of the hole, I place in it a sponge, I also reduce the quantity of water that can flow through it; and the more tightly I plug the hole, the less water will pass through it in any given time.

Now, if I suppose the water to be electricity, I get a fair comparison of its passage through good and bad conductors. Heat is developed *only* when the free passage of the electricity is hindered, either by the want of room or the want of conducting power.

(C.) *Development of Light.* — This is probably only an extreme case of heat. If by gradually reducing the thickness of a conductor, or by using bad conductors, I cause the electric force to assume, more and more, the appearance of heat, a still greater diminution will develop light. A fine wire will become warm, hot, glowing, or be fused, according to the amount of electricity present beyond that amount which it can freely conduct. The electric spark is produced by the interposition of a bad conductor, such as air.

(D.) *Chemical Action.* — A succession of sparks passed through ordinary air produces nitric acid, by causing the combination of the oxygen and nitrogen of which the air is composed. Iodide of potassium may be decomposed by an electric spark, if the two wires be placed so that the spark passes through the iodide.

By much greater power water can be decomposed, and the constituent gases recomposed.

But chemical action is much more easily produced by voltaic electricity, and will be spoken of more at length under that head.

(E.) *Development of Magnetism.*—I coil round a fine steel needle the wire of an electric circuit, and I find it has become a magnet—*i. e.*, will tend to set itself north and south, and will attract very light iron bodies or another magnet like itself. This also is more easily and extensively done by voltaic electricity, and I will therefore discuss it as a subdivision of that phase of electric force.

Of these five, B and C are probably the same, excepting in degree. The last (E) is probably a *phase* rather than an *effect* of electricity. Chemical action is the term used to express a concurrent action on two or more substances that are closely together; and probably, if we could distinguish the separate action of the electric force upon each of the constituents, it would be seen that "chemical action" is only the concurrence of two or more phases of A or E—*i. e.*, of attraction or magnetism. Lastly, it seems more than probable that attraction and repulsion are but special cases of magnetism.

In other words, **Heat** is rather a *conversion* of electricity than one of its *effects;* **Light** is probably only an extreme degree of heat; **Chemical Action** is possibly a phase of attraction; **Attraction** is *probably only* a special case of magnetism; and

Magnetism is, I think, only electricity under another name, or, what is even more likely, electricity itself is a phase of magnetism.

"But," I can easily imagine my reader exclaiming, after recovering his breath, "you abolish everything! Heat and light are electricity over again, chemical action is attraction, attraction is magnetism, and magnetism is electricity, or rather, electricity is magnetism! According to this, everything is nothing, and nothing is anything."

I can only reply, with humility, It is not that nature is so insignificant, but that we are—that man is not the proprietor of the world, but the tenant-at-will—that it is not for him to divide the universe into classes, and to bottle, duly labelled, specimens of each. Such terms as Magnetism, Electricity, Galvanism, Heat, Light, &c., simply express the incompleteness of our perceptive powers, and the very elementary stage of our knowledge of nature. We see the same thing many times, under slightly different aspects, and we give it many names.

(3.) **Sources of Electricity.**—Confining our attention to what is called "frictional electricity," we have to consider the question, How is it to be produced? by what means can we impart to any given substance these powers of attraction, repulsion, &c. &c.? The name "frictional" at once suggests one method,—that of friction. For friction *two* bodies are requisite, and both are electrified, one positively and the other negatively. I rub a piece of glass with a piece of oiled silk: the glass is positive and the silk negative. I rub a piece of vulcanite or shellac with flannel: the vulcanite is negative, the flannel positive. The glass and vulcanite are non-conductors; but it is quite possible to develop electric force by the friction of conducting substances, even the best conductors, such as metals. But it is necessary to prevent it being conducted away as rapidly as produced. In the ordinary gold-leaf electroscope this is done; and if the brass top be rubbed briskly with almost any substance, the leaves diverge more or less. When two bodies are rubbed together the electricity is not evident until they are separated.

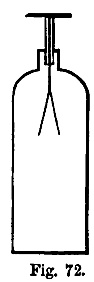


Fig. 72.

But there are other means besides friction of producing even "frictional" electricity, so that it is a question whether the term be sufficiently comprehensive. I press together any two substances, one a good conductor, and one a bad one. On separating them *quickly*, both are found to be electrified. So that *pressure* may be considered as a means of developing electricity.

Cleavage is said to develop electricity. This method is most easily shown in minerals having lines of cleavage. Thus a plate *of mica cut in* this way, and the parts separated quickly, will show

signs of the presence of electric force. It is necessary that the separation should be quickly made, otherwise the electricity is rendered inapplicable from the positive and negative forces recomposing and consequently neutralising each other.

Some minerals show signs of electricity when their temperature is raised or lowered. In this case, when the temperature is rising the mineral is really a magnet, one end being positive and the other negative. While it cools the poles of the magnet are reversed, but it is still really a magnet. If it be broken, each part is a magnet, showing that the polarisation extends throughout, as in an ordinary magnet. This method of developing electricity from heat comes more prominently before us when we consider **Thermo-electricity.**

(4.) **Conduction of Electricity.**— All substances may be classed in three groups:—

1. *Good conductors*—along which electricity passes without interruption, and without giving any sign of its presence.
2. *Non-conductors*—along which electricity cannot pass.
3. *Bad conductors* — along which electricity passes with more or less difficulty, and with more or less development of heat.

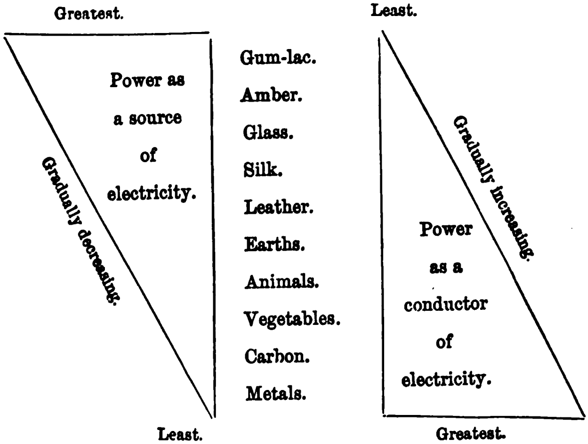
Thus, while a current passes unobservedly along a good conductor, and not at all along a non-conductor, its passage along a badly-conducting substance is marked by heat and light. A spark between two good-conducting substances will pass through gunpowder without igniting it, but if a badly-conducting substance be introduced into the circuit (so as to retard the passage) heat will be developed and the powder fired. Thus, if I place a little powder on a discharger, a spark will merely scatter it somewhat, but a piece of wet string interposed will so retard the speed of the current as to set fire to the powder. I have discussed the conduction of electricity in the chapter on "Conduction."

(5.) **Conductors and Non-Conductors of Electricity.**— In the plate machine, the same substance, and the same piece of it, serves for the development of electricity and for the insulation of it. Thus the outer zone of the glass is the means of the electricity being present, while the central portion prevents its passage and escape by the handle.

Conversely, the brass conductor serves as the best means of conveying the electricity, though no amount of friction on the surface of the brass itself will develop any. And it will be found, generally, that substances on the surface of which electricity can be developed will not conduct it; and, conversely, substances on the surfaces of which electricity cannot be developed will serve to conduct it. But *insulated* conductors become practically nonconductors.

Conductors.	*Non-Conductors.*
Metals.	Gum-lac.
Carbon.	Amber.
Vegetables.	Glass.
Animals.	Silk.
Earths.	Leather.

These are only a few of the most familiar of the substances that can serve either as conductors of electricity or as sources of it. The most general theory is that every substance is capable of both—*i.e.*, that every substance can be electrified, and can also conduct electricity; but that the more it can do one, the less it can do the other. Thus in the following list:—



It is not meant, in any way, to convey by the above diagram that the power as a source decreases in regular amount for each substance, or that the conducting power increases regularly, but only that as the power as a source increases, so the power as a conductor decreases, and conversely; so that when a substance is a good source of electricity, it is useless as a conductor, and a good-conducting substance is useless as a source.

The power of substances to conduct depends much on the atmosphere. Dry air is a non-conductor; and therefore, a body mounted on glass legs is insulated from the ground if the air be dry. But if the air be moist, then the watery particles in it convey away the electricity (water being a good conductor) and also moisture will collect on the surface of the glass legs, and will serve as a conductor to the ground. It is therefore necessary to

perform experiments in a warm room, since otherwise the air may contain moisture, which will dissipate the electricity as rapidly as it is excited.

Electricity may be conveyed to any distance by means of suitable conductors, or kept within any given limits by means of suitable insulators. But the greater the surface over which the charge is diffused, the weaker it becomes at any given point; just as any given quantity of water becomes more shallow when poured from a smaller to a larger vessel. So also any conducting substance, if charged, can only be insulated to a certain degree; for when the body is fully charged, any excess of electricity will discharge itself in the form of a spark towards the nearest conducting substance.

(6.) **Nature of Electric Spark.** — The passage of a spark from one conducting substance to another must be considered as the development of heat (in a sufficient degree to cause luminosity) owing to the retardation of the current by the badly-conducting quality of the air. The same result is obtained by passing a current through any other badly-conducting substance. Thus, if I bring two points nearly together in the middle of an orange, an apple, an ivory ball, or anything similar, the whole of the ball (or apple, &c.,) will become luminous by means of the spark that passes through its centre.

It seems that electricity requires a conducting substance, and that it cannot pass across a vacuum. Air conducts better the more rarified it is, for a spark may be obtained from a good machine of four or five feet in length through a tube of rarified air, when, through ordinary air, from the same machine, one of sixteen or eighteen inches would be the longest possible. The length of the spark seems to increase as the density of the air is reduced, but if the tube be altogether exhausted it seems impossible to get a spark at all.

Electricity is discharged much more readily from angular than from rounded surfaces. From the spherical knob of a conductor the electricity will pass in sparks to the knob of a Leyden jar, but if I insert a pointed wire, the electricity will be given off in a constant stream of fine threads of light, resembling a small broom. From the surface of the knob it can only escape in sparks, each of which discharges an accumulation, but from the point it is given off as rapidly as it is generated. But in either case its passage through air (which is a bad conductor) is marked by the development of heat and light, owing to its retardation.

It will be noticed that the conductor of an electrical machine is rounded in every part, great care being taken to prevent there being any angular projections. The electricity, diffused equally over the whole surface, finds no one point specially favourable for discharge, and so every point becomes charged to its utmost containing power before any is given off.

Fig. 73 shows an electric "brush" given off by means of a short wire from the prime conductor of a machine. Before I insert the wire, I get, at intervals, a series of sparks from the conductor to the knob of the Leyden jar. But when I insert the wire, I get, instead of the sparks, a number of very fine threads of continuous light issuing from the point of the wire, even if there be no Leyden jar.

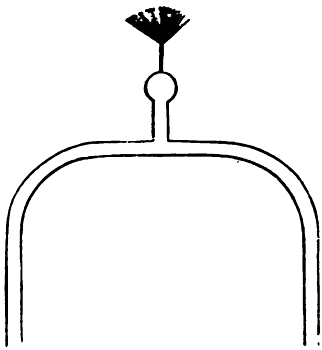


Fig. 73.

The conditions of radiation seem to be the same for electricity as for heat. A polished cover is better for keeping meat warm than a rough one, any points, however small, assisting radiation of heat. Precisely the same is true of electricity. A polished and rounded surface favours the retention or accumulation of electricity. Points, however small, favour its radiation. The "spark" is the discharge of an accumulation which the rounded conductor can no longer retain; the "brush" is an immense number of such sparks, very small, and radiated so rapidly (because of the diminished power of retention, owing to the pointed wire) as to appear like continuous lines of light.

(7.) **Nature of Electricity.**—It may be said, then, that any substance will, by friction, produce electricity, but that only some substances can conduct it. Those that do conduct become, practically, non-producers of electricity, because so fast as it is developed so fast is it carried away. All substances are by nature divided into conductors and non-conductors, or rather into good and bad conductors, and this divides them also into electrics and non-electrics, since only bad conductors can be used as electrics.

But just as all substances are practically divided into two classes, electrics and non-electrics, so all electrics are themselves divided into two classes, of which the electricities seem to be opposite in character, though alike in properties. This division is a natural one, though the place of any given substance is not fixed, but variable.

There is evidently a close connection between electricity and heat. Electricity retarded develops heat; heat produces an electric current if two metals, of unequal conducting powers for heat, be warmed when forming part of a metallic circuit. Is it possible that heat and electricity are but two phases of one natural power, and that the rapidity or direction of the vibration determines in *which it shall* be manifested? Again, the vibrations of an electric

current deflect a magnetic needle at right angles to its path, but not an ordinary needle. What is the difference of condition between an ordinary piece of steel and the same when magnetised? Is it not that in one the atoms are arranged irregularly, and in the other regularly, their poles being held together by magnetic force? But then, what is this magnetic force? Is it a vibratory state of the poles of the atoms?

If so, may not the attraction and repulsion of magnetism and of electricity, and also the influence of one on the other, be really due to one and the same cause—*i.e.*, to the direction of this vibration? It seems not impossible that while the vibrations of heat are to and fro in straight lines, those of electricity are circular, there being somewhat the same difference as between the wire of a chair-spring when compressed and when extended. It may be that the vibrations of an electrified wire coincide in direction with those of a magnet when they are at right angles, but interfere with each other when they are in the same direction; or that the vibrations of electricity can pass between the polarised atoms of a magnet, but not across them, owing to the magnetic attraction being more powerful than that of cohesion. It may be from one or both of these reasons that a magnet is deflected when near an electric current.

But all this is almost gratuitous theory, and must be brought to the test of actual experiment. When any one has, as so very few of us have, time and ability to devote to experimental researches, it is important to start with some general theory, even if it be afterwards proved untrue. On entering a new country, any outline map is useful, as giving direction and consistency to our efforts at progress, but we should be careful to be guided by what we observe rather than by our map, and to be prepared to remodel and alter to any required extent by observed facts.

Theory should be founded on fact; but facts are more frequently discovered in trying to prove theories than by isolated efforts. The great danger is lest any theory so get possession of the mind, that facts telling against it are unconsciously disregarded or not fully credited with all the consequences that follow from their existence. It is the work of a student of nature to believe what he knows rather than what he thinks, but to take especial care that he does really know what he believes to be the facts of the case.

Heat affects the volume and temperature of all things to which it is communicated: electricity does not alter the volume nor (if freely conducted) the temperature. Heat affects the whole mass of a body: electricity is diffused over the surface only. This limitation is in the nature of electricity, not of the substance electrified, for if any electrified substance be divided, each portion will be as capable of being electrified over its whole surface as the original body. Probably if any substance could be electrified throughout its entire mass, its volume might be affected in the same manner as by *heat*. *Magnetised* bodies *do* alter in length.

If I electrify a body, to however great an extent, the whole excitement is confined to the surface; and if it be more than the given area of surface can contain, it will fly off through the air (which is a bad conductor), rather than penetrate to the interior of the electrified body. This is because of the self-repellent nature of the excitement conveyed.

It is this instantaneous passage of the excitement, whatever the real nature of it may be, to the surface of any substance to which it may be communicated, and the apparently total freedom of every other portion of the body from even the smallest share of it, that has suggested the idea of a fluid having an existence entirely independent of the body electrified, and capable of passing from one substance to another, or of being divided between several. But against this idea there comes up :—1. the difficulty of imagining the actual transfer of even the most subtle fluid at the speed at which electrical effects do travel; 2. the fact that no difference in weight is perceptible whatever amount of electricity be spread over any substance; 3. the evident connection between heat and electricity; 4. the fact that heat itself was long supposed to be such a fluid, upon very much the same kind of evidence, and that this theory has given way before further observation.

A third contrast between heat and electricity is the rapidity and completeness with which the one can change its place as compared with the other. If I put together two bodies at different temperatures, they gradually acquire equilibrium; but if I put together an electrified body and an unelectrified, they are both instantaneously electrified—not gradually, with the extra velocity possessed by electricity, but at once, and completely. This may, however, be a consequence of the second difference, that a heated body is heated throughout, but an electrified body is excited on the surface only.

A fourth, and perhaps the most striking contrast, is, that while heat can only be communicated, electricity has an attractive and a repelling force. It is this fact that has, more than any other, suggested the idea that electricity may be a vibration of a circular or corkscrew character, and that the difference between positive and negative electricity is the difference between a right-hand and a left-hand screw.

If it be imagined that glass, when rubbed with silk, is thrown into a vibratory state in which circular vibrations turn in one direction, and that when resin is rubbed with wool the vibrations excited turn in contrary directions, we have a state of things that may be considered capable of accounting for the attraction and repulsion of positive and negative electricity. But it must be borne in mind that the different excitement is not owing to the nature of the glass, nor of the resin, but the difference between the rubbed and rubbing surfaces. Thus rough glass excited by means of oiled silk becomes positively electrified, and the silk

negatively; while if I rub the same piece of glass with a piece of flannel, it becomes negatively electrified, and the flannel positively. But if I rub a piece of smooth glass with either silk or wool, it is positively electrified, and both silk and wool negatively. Again, if I rub the smooth glass on the back of a cat, it becomes negative, and the cat's back positive, so that the smooth glass, rough glass, silk, and flannel, can all be electrified either positively or negatively, and therefore it cannot be that any of these is by nature either positive or negative. Precisely the same thing is evident in voltaic electricity, where zinc is positive in combination with copper, silver, platinum, or carbon, but negative when arranged with calcium, lithium, sodium, or potassium.

But in voltaic electricity, which is excited by chemical action, we know that the element which is most readily acted on by the liquid in which it is immersed is therefore positively electrified. But it is not so clearly evident what is the reason of the difference in the case of frictional electricity. It is, however, very probable that conductivity for heat has a close connection with the development of electricity. Flint-glass is a better conductor of heat than flannel, but a worse than silk, and is positively electrified by silk, but negatively by flannel—*i.e.*, in this case the worst conductor becomes positive, the better conductor negative.

The facts of thermo-electricity, in which electrical effects are developed by joining together and heating two metals of different conductivity for heat, give further support to the idea that just as heat is "a mode of motion," so electricity is a mode of heat, or rather another "mode of motion." I have discussed this subject more completely in the concluding part of the book.

(8.) **Transference of Electricity.**—If I have my machine in good working order, I can collect on the prime conductor a considerable quantity of electricity. How can I transfer this? What laws will govern the transfer? What will be the result to the conductor, and to the body to which the electricity is transferred?

The conductor being fully charged (*i.e.*, having on its surface a good amount of electricity), I present to it a piece of metal held in the hand. Nearly the whole of the charge passes from the conductor, through the piece of metal, through my body, to the earth. I say "nearly the whole of the charge," because what really takes place is this: The electricity is kept on the conductor by the surrounding air, just as water is kept in a vessel, the air being a non-conductor. But as soon as I bring the piece of metal (say a brass rod) in contact with the conductor, I open a path for the electricity, just as I should let water out of a tub by boring a hole; and the conductor, metal, myself, and the earth, all being in electrical connection, form, electrically, one body, and the whole amount of electricity is diffused over this compound body. The earth being so immensely the larger portion, receives

very nearly the whole, but a proportionate, and therefore very small, amount still remains in the conductor. In the course of this "discharge," as it is called, I receive a "shock," unless the amount be very small—*i. e.*, my body being a sensitive substance, I am conscious of the passage of the electricity through it.

This is usually said to be felt at the elbows, shoulders, &c. (*i.e.*, at the joints of the body), and this is accounted for by the same theory that explains the destruction frequently caused when buildings are struck by lightning (p. 162). It is said that if the bones were all in actual contact, the flash of electricity would pass at once to the earth without giving any shock, but that it has to jump from bone to bone at the joints, and the delay (and consequent accumulation) is the cause of the jar that is felt. This assumes that the bones are the conducting substance, and not the flesh, or else the electricity would remain on the surface and not reach the bones. In this case there would be a shock at the entrance to the body, and at the point of leaving, since there the flash would have to pass through the flesh to the bones, and from the bone through the flesh to the ground. The danger in receiving shocks, the "start" that is always felt, and the natural reluctance to experiments on this point, all probably tend very much to keep the knowledge of it very imperfect.

If, in discharging the conductor of a machine, I hold the brass rod in contact with it, while I am charging it, I carry off the electricity as fast as it is generated, and receive no shock; because, though I receive the same amount as before, I take it in small quantities. The earth, myself, and the conductor, being all joined together, the electricity spreads at once over the whole, and accumulates only in the earth.

If the conducting substance that I present to the conductor be insulated, the electricity, as before, spreads over the whole of the surface presented to it, but does not reach the earth. Thus, if I present another conductor, carefully insulated, it receives half the amount accumulated on the first conductor, which itself still retains half, because its surface is equal to the second surface, and the whole amount present is distributed equally over the whole area presented to it. If I present a metallic ball (whether solid or hollow matters not, as it is a question of surface, not mass) it shares with the conductor, according to their respective areas of surface; and if to this ball I present a second ball, the same division, according to area of surface, takes place. Generally, I may say that any amount of surface (in whatever number of pieces) will have any accessible amount of electricity diffused equally over the whole. However slight may be the connection, so that it be of conducting material, between any number of surfaces, these may be considered as one.

There is, however, one very striking exception to this rule; and here, more than in most exceptions, "the exception really does *prove the rule*." If I have one ball fully electrified, and I cover

it with the segments of a hollow sphere of larger size (it may be much larger), and bring the two into contact, the whole of the electricity spreads over the surface of the outer sphere, leaving the inner one entirely free from even the least trace. If the inner surface of the outer touches the outer surface of the inner, the transference is at once made; but if there be an interval of space between, as there will be if one be much larger than the other, then I can make the necessary contact by passing a fine metal rod or wire through the outer until it touch the inner. This wire will be quite sufficient road for the passage of the electricity.

If I reverse this experiment by electrifying the outer ball, and placing the smaller, unelectrified, within it, I shall not be able to transfer the charge from the outer to the inner, though if I take out the smaller ball and put it beside the larger, the whole amount of electricity will be at once divided between them.

This illustration shows that electricity will always go to the outside of every substance, and that if one electrified body be put within another, the whole charge will be collected on the surface of the outer.

This may be shown in another and a pretty manner. "Faraday's butterfly net," as it is called, is a conical net of any flexible conducting substance, having a wire-frame round the base, and a silk thread at the apex. By this thread it may be reversed, so that either side of the net may be made the inside or outside at pleasure, while the silk thread being a non-conductor, none of the electricity is lost in turning it inside out, even when charged. I charge the outside, and by testing show that the inner side is quite free from any trace of excitement. By means of the silk thread I turn the net so that the outer becomes the inner side and the inner side the outer. On testing again, I find that every trace of the electricity has passed to the side which was before quite free from it, so that the other, which (when the outside) had all, has now (as the inside) none whatever.

a b c shows this conical net supported upon a stick, and having a silk thread at *c*, partly inside and partly outside. By means of this I can give the net the position either of *a b c* or of *a b d*. In either case all the electricity will be always found on the outer surface, no matter to which it may have been communicated, or how many times it may be changed.

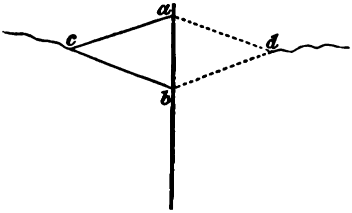


Fig. 74.

So that we may safely, from these facts, infer that electricity will always remain *on the surface*, will extend over the whole of

any surface or surfaces, but will not extend from one surface to another unless there be a connection between them, or, that the charge is so great that it can pass through the air, which it will not do until the charge be strong.

I have said that the electricity on the conductor is kept there by the surrounding air, which forms as real a covering as a tub to water, and that it does not pass through this aerial coating until a road be opened to it by some conducting substance. Living as we do in the midst of air, moving in it without being conscious of its presence, seldom having its properties brought to our minds, it is difficult for us to realise its actual existence, and to remember that it is a reality, ever present, ever active, existing not merely for us to breathe, but as an important though invisible constituent of the world, influencing almost everything it comes in contact with.

Air is a non-conductor of electricity, but is not unaffected by its presence. If I electrify the inside of a Leyden jar, the outer side is affected by the excitement of the inside, and this influence is exerted through the glass. The inside coating being positive, the outside becomes negative, and the theory is that the particles of the glass are polarised—*i.e.*, all arranged in one direction. Each particle is supposed to be electrified, one side negatively and the other side positively, so that the two metal coatings and the polarised particles of glass are arranged alternately positively and negatively, just as the elements of a voltaic pile.

Exactly the same is the result upon air if it be placed in the same position. If I place the metal coatings of a Leyden jar one within the other, but without the jar itself, so that the place usually filled by the glass is filled with air, the particles of this air will be polarised in exactly the same manner as the particles of glass. This may also be shown by placing two metal discs, or conducting substances in any shape, near to each other, with a small interval between them. The ordinary phenomena of induction at once present themselves, the air between the conductors being polarised.

But it can scarcely be imagined that this can take place only when the air is in a thin stratum. The force may decrease as the stratum of air becomes thicker, but there must be still the force, whatever be the amount of air between the two conducting substances. So that when we speak of air preventing the escape of the electricity from any substance, we must bear in mind that the air itself is polarised in the line of contact, and that this polarisation probably extends the further the greater the amount of electricity present.

If a Leyden jar be fully charged, and more electricity be forced into it, the result is usually that a discharge takes place through the glass, which is cracked at the point where the communication occurs, and which is generally the weakest or thinnest part of *the jar*. Just the same occurs when the induction takes place

through air. If I place the knob of a Leyden jar near to the conductor of a machine it is gradually charged by the passage of a series of flashes, or sparks, from the one to the other. That is, the air between the two is polarised, as is the glass of the jar. When the accumulation of electricity has become sufficiently great, it leaps across the interval of space through the air in the form of a spark.

If, however, I place a pointed rod in the conductor, the electricity will pass more quickly to the jar; or if I place a wire ending in a small knob, it will pass more rapidly than from the large knob of the conductor, but not so rapidly as from the pointed wire. Generally the larger and more uniformly spherical a surface the less readily will the electricity leave it, while a point prevents any accumulation, from allowing it to escape as rapidly as generated.

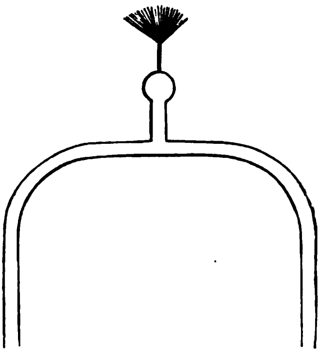


Fig. 75.

If a conductor be made to terminate in a point (as by attaching a wire to it), the electricity will pass away, not as a spark, but in a continuous glow, distinctly visible, but scarcely bright enough to be called sparks. This "glow" will radiate from the point as from a centre. If I put a bundle of wires, each extremity will become the centre of such a radiation, the electricity passing into the air. Fig. 75 shows this.

If, having such a collection of points, I place any conductor, such as the knob of a Leyden jar, near to one of them, the whole of the electricity will pass through that to the jar, the others ceasing to glow with any discharge.

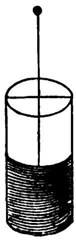


Fig. 76.

It might be asked, How can the electricity on the conductor know which of the wires has the Leyden jar near it? But since this question assumes not only an individuality for electricity, but also a conscious existence, we had better frame the question, What change does the proximity of the Leyden jar make in the conditions surrounding the conductor that the electricity shall be able to pass from the conductor to the jar? It is not a sufficient answer to say that the distance is reduced to within the limits that a spark can cross, unless it be also shown how the electricity collected on the conductor is to be induced to cross the distance. To draw fish from the water it is not enough to drop a line into it. By some means *the fish must be induced* to connect themselves with the

line. So it is not enough to reduce the distance between two conducting bodies (one only of which is charged) to less than the electricity will cross, unless it can also be contrived that the electricity shall cross it.

Air is said to be a non-conductor, yet if the distance be short enough, electricity will cross it in the form of a spark. Therefore air is not, absolutely, a non-conductor, but only a bad conductor. Also, the greater the intensity of the charge, the greater the distance it will traverse. Therefore it would seem that the crossing is not merely a transfer of place; but really something that the electricity *has to do,* and that the greater its strength, the more of this task it can perform. Lastly, in rarified air, the power of conducting seems to be increased—*i. e.,* the electricity can travel a greater distance—*i. e.,* can do more of this required work. Therefore it would seem that this work that has to be done is performed on the air, and that the less air there is the more work can be done, though when there is no air at all, no passage of electricity takes place.

What, then, is the work that electricity performs on the air in passing through it? Why does this work produce light? Why does the presence of a second conductor assist the passage? We have seen that electricity passes through glass in the Leyden jar, and that sometimes the glass is broken by the passage. It is generally found that this fracture occurs at the thinnest part of the glass. Is the action of the electricity on the glass the same as its action upon the air? It is usually considered that the atoms of the glass are polarised—*i. e.,* all arranged in the same direction; but what this direction is, and what determines it, are not so well understood. Assuming for the moment that there are two distinct states of electricity, called negative and positive, it is sometimes represented that the atoms of the glass are electrified negatively on one side and positively on the other, and that they are arranged somewhat thus. This regular arrangement is called polarisation, and it would seem as if this arrangement were really the work that had to be done by the electricity in passing—that this arrangement is really the passing. For we must carefully bear in mind that electricity is not matter, but only a state of matter; that when we say a metal rod is charged with electricity, we mean, not that it contains anything in addition to its own substance, but that its particles are so arranged, or are in such a condition, as to present the phenomena we usually associate with electricity. Just as when we speak of a man being full of anger, we do not speak of anger as an entity, but as a state or condition of the man's mind.

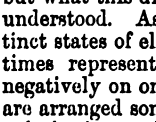


Fig. 77.

Fig. 77 shows the supposed polarisation of the molecules of the glass, very much magnified. It *is not meant* to assert that they are necessarily circular in shape, *but only that* they are probably veritable magnets.

Assuming, then, that the atoms of glass in a Leyden jar are thus arranged or polarised, may we assume that the same takes place with the atoms of air between the conductor of a machine and the knob of a Leyden jar when a spark crosses the interval between them? Further, may we assume that the disruptive discharge through the air corresponds with the occasional fracture of a jar? Then the passage of a spark through air means nothing more than the arrangement or polarisation of the atoms of air, and the distance through which the spark can travel depends upon the power of the electricity to arrange these atoms. Thus, suppose a brass rod a foot in length to be charged with electricity, all the air round it will be acted upon by this force, which will tend to electrify it. If I bring another metal substance within, say, six inches of it, the interval is at once bridged. But is the air unaffected until the second metal body be brought near the first? Or does the electrified body act on the air around it so far as it has power?

Let there be a brass rod in connection with a plate battery, and just so much excited that a spark will pass from it to a Leyden jar placed within six inches. I take away the jar, but still excite the machine by turning it; what is the effect upon the air around the rod? Clearly the force is sufficient to polarise the air for a distance of six inches, because it can pass to the Leyden jar at that distance. Is it, therefore, that all the air surrounding the rod is polarised to a distance of six inches, but no further; and that when any conducting body comes in contact with this stratum of electrified air, it becomes itself electrified by contact? This would undoubtedly be the case if there were nothing to counteract the force exerted by the electricity of the rod; but it must be borne in mind that the particles of air are acted on by those at a greater distance, and therefore themselves free from the influence of the electricity. This second force tends to disturb the first; and so it follows, probably, that the air round the rod is gradually less and less polarised as the distance increases, each atom being acted upon by the outer air with more and more force as the polarising force decreases.

If we can imagine a number of men on a raft, each having a rope which he tries to cast ashore, but which being too short is tossed to and fro by the water, until one, coming within reach of the land, has his rope caught; so we may imagine the force collected on the brass rod trying to pass across the surrounding atoms of air, and prevented by the distance being too great, until at one point a second bar of metal is within reach, and at this point the passage is effected

It is easy to understand how a rope thrown by a man on a raft can be caught by another on land; but it may not be so easy to conceive how the proximity of a conducting substance can enable a force to pass over an interval of non-conducting matter. This really raises *the question, What* is the difference between con-

ducting and non-conducting bodies? Bearing in mind that the conveyance is not of matter, but of motion, it may easily be conceived that that which is most capable of motion may be the best conductor. Thus it would seem much more easy to transmit *motion* through water or air than through a solid; yet we know the contrary to be the case when electricity is the motion to be transmitted. It is much easier to transmit an electric current through a brass rod than through a column of air—*i.e.*, it is easier to move the particles of a metal than of a gas, in the way that they are moved by electricity.

If, therefore, we consider in what respects the arrangement of the constituent atoms of a solid differs from the composition in the case of a liquid or a gas, we may, by taking into account how this particular arrangement will assist the transfer of a motion through the assemblage of atoms, arrive at some suggestion as to the kind of force that is so transferred in the case of electricity.

If a stick, or the thong of a whip, be passed rapidly through the air near me, I feel a certain effect that it has on the particles of air in contact with my face. The particles moved by the stick in its passage move the adjoining particles, these the next, and so on until the motion was received by the atoms next my body. In this way *motion* is transferred—that is, the force that moves one atom is carried on, and on, until it has moved others, while no particle of air moves more than a very short distance from its first place.

In the same way, if I am bathing, and a stone be thrown in the water near me, I feel the motion transferred to the particles of water in contact with myself—*i. e.*, motion can be transferred through water in the same way as through air.

Lastly, if I hold by one end a thin bar of iron, while the other end is beaten on an anvil, I shall be made sensible, by the vibration of the end I hold, that the motion conferred on the particles beaten by the hammer is transferred to the remaining particles; so that it would seem that motion can be transferred from particle to particle in any medium, solid, liquid, or aerial.

Now what kind of motion may be expected to be capable of more easy transmission through a solid than through either a liquid or aerial medium? If I desired to move any object at a distance, I should employ a solid as a means of doing so; thus I use wire for bell-ringing, not a column of water, or a pipe of air; not because these latter would be absolutely useless, but because the solid conveys the impulse I give to one end of it so much better. But this is not the kind of force that we call electricity. This latter is not a mere bodily transfer of a solid as a whole, but rather a motion amongst the particles composing the solid, the whole body still remaining within its original limits.

The wire serves for bell-ringing purposes best, because its atoms are in closer contact than is the case with a liquid or a gas. This enables any one atom to act upon the next to it at once, and

with its full force. If I place ten men side by side, and barely touching each other, any impulse given to the first will not be much felt by the second, still less by the third, and least of all by the last. But if the men stand quite close to each other, the force will be much more completely transmitted. Lastly, if they are crowded closely together, with arms around one another, any pressure put upon one will be felt almost equally by all.

In just the same way the atoms of a solid are closely crowded together, and any force communicated to one is transmitted with but little diminution throughout. But the force which we call electricity is evidently not one of mere transposition, for the reasons just given. Also it is not one of mere vibration, for then it would not differ from the force we call *heat*. It differs from this force, heat, in its attractive force upon small magnetised needles. It may therefore itself be called a kind of magnetism: and just as a magnet is supposed to become a magnet by having its particles arranged, or polarised, may we suppose that the passage of an electric current is really the arrangement or polarisation of the successive atoms of the substance through which it passes.

It is easy to conceive that such a force will pass much more readily from atoms of a solid than of a liquid or of a gas, and that therefore solids will, as a rule, be better conductors of electricity than either liquids or gases—*i.e.*, the power of conducting electricity really means the capacity for being easily polarised. So that a substance, of which the atoms have a certain amount of freedom of movement amongst themselves, is a conducting substance; while another, in which the atoms are more rigidly fixed, is a non-conductor, or at best a bad conductor.

It would seem, therefore, that to constitute a good conductor of electricity, both cohesion and independence of the atoms are necessary; cohesion, to give the greatest transfer of force—independence to enable this force to act with the greatest advantage. These qualities are, to a certain extent, antagonistic, and those substances are the best conductors where the two opposing forces are so tempered that any given impulse produces the greatest result in the way of such polarisation as we suppose electricity to be.

We may now try to answer the question we found it necessary to ask just now (p. 149),—How can the proximity of a second good conductor enable a current of electricity to pass from a good conductor across an interval of badly-conducting substance? Evidently by removing the disturbance that prevents the polarisation of the atoms of the bad conductor. Thus, in the case in point, the presence of a Leyden jar near the conductor of a plate machine, enables a spark to cross the intervening space of air, which is a bad conductor. The same force is exerted on the air whether the Leyden jar be there or no; but in one case the air beyond the influence of the current disturbs the air within this influence, and undoes the work as rapidly as it is performed, while the jar not *only does not* disturb the force exerted on the inter-

vening air, but by being itself easily polarised, it offers a ready road for its continued passage. It would be of little use for a shipwrecked sailor to be able to swim to shore, if the shore, when reached, were so precipitous and bare as to afford no foothold.

But why does the passage take the form of a spark? The passage of the current means no more than the polarisation of the consecutive atoms of the air: why should this rearrangement emit light? We have just seen that electricity differs from heat in that heat is probably only *vibration*, while electricity is also *arrangement;* one, therefore, implies more motion than the other, and probably when the arrangement of electricity is difficult, the force takes the form of heat. That this is so, we infer from many facts. Silver is a much better conductor of electricity than platinum, and if I send a current of electricity through a chain of which the links are alternately silver and platinum, the links of the worse-conducting metal will become heated much more than the silver links; that is, the force will arrange the atoms of silver with but little difficulty, while it will be much more resisted in the case of the platinum atoms. This resisted force will become heat, and even light, for the platinum links will become vividly visible by reason of the great heat to which they are subjected.

It is therefore tolerably clear that electricity can become heat, and that heat can become light; and also, therefore, that electricity, passing through heat, becomes light, if resisted with sufficient force. It is also clear that this resistance is met with in the case of bad conductors, and especially so in the case of what are called non-conductors. This is really only a truism: it is only saying that there is most resistance where there is most difficulty of arrangement. But we see clearly that resistance converts electricity into heat, and heat into light, and that this is why electricity passes across bad conductors in the form of, or rather accompanied with, a spark.

(9.) **Velocity of Electricity.**—The passage of an electric spark is instantaneous. Speaking literally, it occupies no time to pass from one point to another. By actual experiment it has been shown that the velocity of an electric spark is 280,000 miles per second—*i. e.*, ten times the circumference of our globe. This is the normal speed along an almost perfectly-conducting substance. If the conduction be not perfect, the passage of the electricity is retarded and heat developed.

Thus, if I pass a current of frictional electricity along an iron chain, the conduction will not be so perfect as in the case of iron wire, and not only heat but light will be developed. Wherever there is the least interruption to the passage of the current it will jump across in the form of a spark.

We have seen how the velocity of light was ascertained by means of observations made upon the moons of Jupiter, and that

the speed is so enormous that no ordinary mode of measurement seemed available. But electricity travels with even greater rapidity. How shall that be measured? Sir Charles Wheatstone answered this question by a most elegant experiment, and one so simple that, instead of requiring the universe for its measuring-ground, it can be performed in an ordinary-sized room. A Leyden jar, a mile of copper wire, a small mirror, with apparatus to set it in very rapid revolution, and six small metallic knobs, make up the necessary apparatus for measuring a velocity that outstrips even that of light—that, if uninterrupted and unretarded, can *encircle the world ten times in a second.*

A B E F D C

A is connected with a Leyden jar; so also is C. There is a continuous wire from the jar through A, B, E, F, D, C, back again to the jar, excepting the three very short intervals between A and B, E and F, D and C. Between the jar and A, and between the jar and C, the distance is very short; between B and E, F and D, the current has to pass through a considerable length of wire, say a quarter of a mile between each.

The passage of the current is shown by a spark at each of the three breaks, A, E, and D; and the value of the experiment depends upon the measurement of the intervals between these sparks, just as I might estimate the speed of a railway train by measuring the time it required to pass from station to station. It is evident that in passing from B to E the current travels a quarter of a mile, and the same from F to D. If the spark at E F be any time after the spark at A B, that time is what is required to pass through a quarter of a mile of wire. The difficulty is to render so short an interval of time appreciable. This is done by means of a mirror which is made to revolve very rapidly—some hundreds of times per second. The sparks, as they occur, are reflected in the mirror, and the reflection can be sent to a screen, or to a second mirror. Three bright lines | | | would be given if the three sparks were absolutely identical; but if between each spark the mirror had time to make a partial revolution, then the lines might be expected to be thus | | | Such a variation from the straight line would mark a very small interval of time. Let the mirror revolve 400 times per second, an interval of $\frac{1}{4000}$ of a second would correspond with $\frac{1}{10}$ of a revolution. The effect of this may be realised by holding an ordinary looking-glass near a candle, so that the reflected light is made to fall on a second mirror. Now, move the first mirror through a small angle, say 30° (less than $\frac{1}{10}$ of a revolution), and notice the altered position of the light in the second mirror.

Sir C. Wheatstone performed this experiment, and found the

three sparks to be reflected, not | | | as they would be if they occurred absolutely at the same time, nor yet | | | as they might be expected to be if they occurred in succession, but | | | denoting apparently that the two sparks at the end occurred simultaneously, and the middle one somewhat later. From this Sir C. Wheatstone inferred the velocity to be 288,000 miles per second, estimating the time that the middle spark occurred after the end ones as the time required for electricity to travel through a quarter of a mile of wire. The calculation is somewhat thus: The mirror was revolving 800 times per second. If the sparks had been at an interval of one revolution the velocity would have been $\frac{1}{800}$ of a second for $\frac{1}{4}$ a of mile = 200 miles per second. But the interval between the two sparks was only $\frac{1}{1440}$ of a complete revolution; and therefore the velocity is 200 × 1440 miles per second.

It is most probable that electricity itself occupies literally no time whatever if we could use an absolutely perfect conducting medium, and that the velocity is rather the time required to overcome the resistance of the particles of the medium than the time required for the current itself to be propagated. But this "overcoming the resistance of the particles of the medium" is really the electric current, and the velocity of electricity is not, therefore, an absolute velocity, but varies with the medium. No medium is absolutely without resistance; and just as we say the velocity of Light, Sound, or Heat varies with the medium whose vibration is the light, sound, or heat, so the velocity of electricity varies with the medium *whose molecular arrangement is electricity.* The velocity, 288,000 miles per second, means no more than that copper wire of the kind used for the experiment can be polarised at that rate. It is no more truly the velocity of electricity than is the rate at which it travels through any other medium.

(10.) **Induction.**—If I hold an excited glass rod or stick of wax near the electroscope, the gold-leaves recede from each other, and come to rest again as I withdraw the glass or wax. This is the result of attraction through space; for no passage of electricity takes place from the rod to the leaves. The presence of an excited substance is sufficient to disturb the leaves, and its withdrawal allows them to return to their normal state of rest.

But if, while the excited rod is keeping the electroscope in a disturbed condition, I touch the cap of it, a result follows that is instructive if carefully examined. After I have touched the cap, the leaves of the electroscope do not diverge under the influence of the excited rod, but do so the instant I remove it; so that I seem to have introduced something, by my mere touch, that reverses the previous conditions. Let us consider what this is.

When I bring the excited rod near the cap of the electroscope, the leaves diverge. From this I might infer that they were both charged with similar electricity—*i.e.*, both positive, or both negative. Assuming the truth of the single-fluid theory, this is evidently what I might expect; for a glass rod, being positive when excited (*i.e.*, having more than its normal quantity), would drive some of the electricity from the cap to the leaves; so that the cap would have less and the leaves more—*i.e.*, the cap would be negative and the leaves positive. This would be induced by the power of the rod to approximate, as far as possible, the electrical state of bodies within its reach to an equilibrium with its own. Thus the rod having more and the cap less, the two together are in equilibrium, while the quantity driven from the cap goes to the leaves, and would escape altogether, but that the air round the leaves, being a non-conducting substance, prevents it. So long as I keep the rod near the cap, this state continues, and the leaves remain diverged; but if I touch the cap with my finger, I introduce a new source of electricity, and the leaves at once come together; they being, through my finger, in communication with the earth, equilibrium is at once restored.

When I take my finger away, the leaves remain at rest, because the presence of the excited glass rod stands in the place of so much electricity in the cap of the electroscope, and the leaves remain in possession of the amount they obtained through the contact of the finger; but if I remove the rod, the cap and leaves become again, as it were, one electrical whole, and the total amount of electricity is equally diffused over the whole body—that is, the leaves part with some to the cap, and thus remain negatively charged, the result of which is an immediate divergence.

It may be useful to recapitulate the facts of the experiment, which illustrates so well the very important quality of "**induction**," which is the term used to express this *temporary* change in the electrical condition of a body in a normal electrical state when subjected to the influence of any substance in a state of electrical excitement.

1. The cap and leaves being in connection with each other by means of a brass rod, must be considered as one body for purposes of electricity, and this is in its normal electrical state. Fig. 78.

2. I hold near the cap an excited glass rod, and some of the electricity is driven from the cap to the leaves, which immediately diverge, by reason of the positive charge thus forced into them. If I remove the rod, the cap and leaves resume their normal condition. Fig. 79.

3. I touch the cap with my finger. The result is that the surplus electricity of the leaves passes away to the earth through my body, and the leaves come to rest. The condition of the cap remains unchanged, since the positive electricity of the glass rod really stands in the *stead of* so much in the cap, which is thus

negatively charged, while the leaves are in their normal state. Fig. 80. Removing my finger, I leave the cap and leaves in this condition.

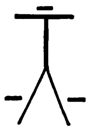


Fig. 78.

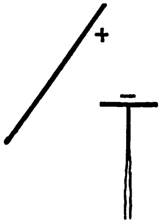


Fig. 79.

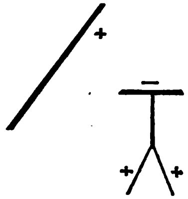


Fig. 80.


Fig. 81.

4. I remove the rod. The cap, no longer under the influence of its presence, withdraws some of the electricity from the leaves to restore the equilibrium between them and itself, and they, being thus negatively charged, diverge. The rod held near neither communicated nor received anything to or from the cap, and the electroscope is thus charged with as much less as it gave off through my finger. Fig. 81.

5. By touching the cap again, or placing it in connection with any conducting substance, I restore just this amount, and the electroscope is once more in its normal condition.

If, instead of a glass rod, I bring near the electroscope a stick of wax, shellac, or other resinous substance, the results will in all cases correspond with those just described, but the electrical conditions will be reversed throughout. Thus—

1. The cap and leaves are normally at rest as before.

2. An excited stick of wax draws some of the electricity from the leaves to the cap, and the leaves diverge, from being negatively charged.

3. By touching the cap I cause sufficient electricity to enter to bring the leaves to rest, the cap continuing positively charged under the influence of the wax.

4. The rod being removed, the surplus electricity held imprisoned in the cap flows partly over the leaves, and they diverge, from being positively charged.

5. By touching the cap I draw off the surplus electricity, and the electroscope is again in its normal state.

The two results may be summed up by saying that by means of an excited glass rod I can draw off electricity from the electroscope; and by means of an excited stick of wax I can force electricity into it; and in neither case will there be any evidence of *the change* until the glass or wax be removed.

It being very important, to a right comprehension of Induction,

[illegible]ults be understood, I give the two sets in parallel

[illegible]xcited *glass rod near an* [illegible]ope.	*I hold an excited stick of wax near an electroscope.*
[illegible]es diverge from being over-[illegible]ed, electricity being driven [illegible] the cap.	The leaves diverge from being under-charged, electricity being drawn to the cap.
[illegible]h *the cap.*	*I touch the cap.*
[illegible] overcharge passes from the leaves, which come to rest.	The undercharge is compensated by electricity drawn in.
[illegible] *remove first my finger and then the rod.*	*I remove first my finger and then the stick.*
The leaves diverge from being under-charged, electricity being drawn from them to the cap.	The leaves diverge from being over-charged, electricity being driven from the cap to them.
I touch the cap again.	*I touch the cap again.*
Electricity passes in, and the leaves come to rest.	Electricity passes out, and the leaves come to rest.

If I remove the rod while my finger is on the cap, electricity passes in or out, as the case may be, and the leaves are restored to their normal state at once.

If I connect the knob of one of a battery of Leyden jars, all the others being in contact with that are similarly charged by conduction, but they may be charged in the same manner by induction. Thus, if instead of connecting the jars by joining all the knobs—*i.e.*, all the interior coatings—I connect the outside of each with the inside of the next, I charge the whole battery more rapidly, and with less labour than before.

For example, to charge a battery of six jars. The interior coatings being connected, and the outer ones in connection with the ground, I have practically a jar of large size, having an area of six times the area of one of the small ones. This consequently requires the communication of six times the amount of electricity that would charge one of these small ones. Suppose 50 turns to charge one, then 300 turns will charge the whole six, as much electricity being driven off to the earth from the exterior of each jar as is communicated to its interior from the conductor.

But if I arrange them in alternate communication, and insulate them from the earth, then the electricity communicated to the interior of the first jar drives an equal amount from its exterior, but this cannot go to the earth, because of the insulation. It is conducted to the second jar, and the electricity driven from the outside of this is communicated to the inside of the third jar, and so on, until the whole battery is charged by the same number of turns that is required to charge one jar, with an addition sufficient to compensate for the loss by radiation during the passage from jar to jar.

Why then take the trouble to charge a battery by the longer method? Because the difference in labour is less than that re-

quired to arrange the jars so as to insulate them, and to arrange for the discharge of the whole battery.

Fig. 82 shows this method (called the method of *cascade*) by which the charge given to one jar charges a whole battery. A, B, C, are three Leyden jars standing on a glass tray, M M. The inner side of A is excited by D, the conductor of a machine, and the outer side is also excited by induction from the inner. By means of the wire *a* (connecting the inner coating of B with the outer coating of A) the inner side of B is charged by conduction, and the outer by induction. In the same way C is charged. All the insides are positive if D be positive, and the outsides negative. The outside of the last jar must be connected with the ground. M M must be a good insulator, and it is perhaps better if each jar stand upon a separate insulator.

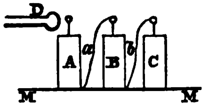


Fig. 82.

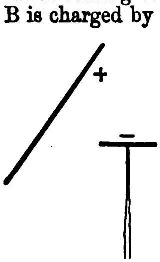


Fig. 83.

We have now to answer the question, What is it that causes an excited glass rod to influence other bodies without communicating anything to them? If I connect the rod and the brass cap of an electroscope by a wire, *both* are positive or negative, as the case may be; if the air only be between them, one is positive, the other negative. When the influence passes through a good conductor, it is called *conduction:* when it passes through a very bad conductor it is called *induction*. The question, therefore, becomes—What is the state of a very badly conducting body when an excited body is held near it? The answer is given graphically in fig. 84, where the molecules are shown to be polarised —*i. e.*, each becomes really a magnet. All these magnets are arranged with their north poles in the same direction when any excited body is brought near. Let us suppose a given number of molecules of air between a glass rod and the cap of an electroscope. The glass is +, the first molecule has its − pole turned towards the glass, and so has each succeeding molecule, so that the last molecule, the one nearest the cap, has turned towards the cap its + pole. This molecule of air is as truly a magnet as any other, however large, and the molecules of the cap are acted upon by the air magnets in contact with it. Their + poles being turned towards the cap, this is consequently negative.

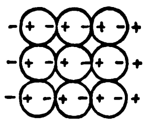


Fig. 84.

The moment I take the excited rod away the polarisation is broken up by the interference of the surrounding air, and the influence upon the brass cap at once ceases. Induction might be *roughly* defined as conduction by means of an unstable conductor.

(11.) **Lightning.**—This development of heat and light from electricity is very perceptible in the case of lightning, which must be considered as a very long electric spark passing from the clouds to the earth. For this to occur the cloud and the earth must be in somewhat the same relation as the Leyden jar and the conductor of a machine. Between the earth and the cloud is a large mass of air, through which the electric current passes (as between the machine and the jar) in the form of a spark.

Just as we can enable the current to pass to the jar without any appearance of light, and without any other sign of its presence, so we can do much to prevent the very great damage done to buildings when they are "struck by lightning." If we connect the conductor and the jar by a fine wire, the whole force is transmitted by this road, and none by the air. If in the same way we connect a cloud and the earth by a thick metal rod, there will be no lightning—*i.e.*, no spark.

But we cannot poke long rods up to the clouds every time a thunder-cloud appears. In addition to the impossibility of reaching the clouds there is the danger of even being near, much less of handling, any substances that offer a ready passage to the electric force. What, then, can be done to diminish the danger of injury by lightning? We have seen, in the case of the conductor and Leyden jar, that any conducting substance interposed between them serves as a road from one to the other. So any conducting substance interposed between a thunder-cloud and the earth may be made such a connecting road, by the passage through it of the electric force. A man's body is a moderately good conductor, and therefore is in danger. Trees are not such good conductors, but are higher; so that it would seem that to stand beside a tree would be a precaution, since the tree, being higher, would be first reached, and would conduct the force to the ground. The tree, being higher, is in more danger of being reached, but the force in passing down the tree might pass from the lower part of the tree to the man's body, and pass through that to the earth, preferring the human pathway as the better conductor of the two bodies. So that, so far from a tree being a protection, it is a danger.

Some trees, such as firs, which contain much resin, are worse conductors than others, such as the elm, and therefore less dangerous.

When a man is "struck by lightning," the body is traversed by the electric force, and the result is usually instantaneous death. Professor Tyndall, who once received, unintentionally, the discharge of a very powerful Leyden battery, describes the result as having been the most utter unconsciousness of everything for a few seconds. The fact that he felt no pain whatever, he considers to justify the inference that the still more severe shocks that cause death produce no suffering, because of this complete unconsciousness.

When a tree is struck in this way, the usual consequence is its being torn to pieces. A mast of a ship, weighing some eight hundredweight, was thus shattered into small pieces, with which the water was covered. So, frequently, chimneys, church-steeples, towers, and other lofty buildings, are destroyed by the passage through them of the electric force, being shattered by the effects of this passage. Such buildings are generally more liable to be struck because of their greater height, which brings them nearer to the cloud.

The means usually employed to protect such buildings is to arrange a continuous metal band, or stout wire, that shall reach from above the highest point of the building to the ground, and thus offer to the electric force an uninterrupted passage. It is estimated that a copper rod, of less than an inch in thickness, will carry off the strongest flash of lightning in safety. Such rods are often attached to all the pinnacles of a building, and connected with one common conductor to the earth. For instance, lead gutters or iron water-pipes will serve as conductors as efficiently as rods specially set up, provided they be in continuous connection and reach to the earth.

But it must be borne in mind that it is not the passage of the electric force, *as such*, that does the damage, but the *development of heat* owing to its being resisted. Down the metal rod it passes in safety, giving no sign of its presence; but its passage through a brick wall is usually marked by destruction. This is probably owing to the resistance of the non-conducting materials, such as bricks, mortar, stones, &c. The great heat developed by the resistance to the electric force converts whatever moisture there is into steam, and this is done suddenly, and with a force much greater than would be expected, when it is not considered what great expansion takes place when water is changed to steam. It is the force of this expansion, and not the passage of the electric force that causes the destruction of trees, towers, steeples, &c.

If the metal conductor be not thick enough to carry off all the electric force, it will be heated by the conversion of part of it into heat. This is sometimes so great that the metal is melted or fused, and frequently oxidised. There are on record many instances of bell-wires being entirely dissipated, leaving nothing but a mark on the wall, and even lightning-conductors have been consumed entirely by charges of electricity too great for them to carry off.

The electricity of the atmosphere is usually, if not indeed always, positive as regards the earth, and is also more intense the higher we ascend. This last has been proved by means of an iron arrow having fastened to it one end of a coil of wire, the other end of which was fastened to an electroscope. This arrow was shot vertically upwards, and it was found that the electroscope showed an increased amount of electricity to be acting on it as

the arrow ascended. Assuming the air to be more and more electrified as the distance from the surface of the earth increases, we should expect that the arrow as it passed upwards would transmit, through the wire, to the electroscope, indications of the increasing intensity. And this is what it does; for the leaves of the electroscope diverge more and more as the arrow ascends. But if the arrow be shot horizontally—*i.e.*, along the surface of the earth—no such indication of electric force is given, for in this case the arrow moves along in air of the same electrical tension throughout.

Electrical sparks pass sometimes from cloud to cloud across the intervening air. In such cases no electric force reaches the earth. But when a discharge takes place from a cloud to the earth, across the air between, a spark, which we call a flash of lightning, passes from the cloud to the earth, showing that the resistance of the air has developed from the electric force a large amount of heat and light. In such cases the discharge reaches the earth, taking in its road any conducting substances that are near, and even turning aside to reach them (p. 161). If there be in the way any high building, such as a church-steeple, it will probably become the pathway of the electric force, and whatever portions of the building be of metal will offer an easy means of passage. If there be a continuous metal communication from the point where the lightning enters to the ground, most likely no harm will be done; but where the pieces of metal are separate, as in the case of bars, cramps, bells, &c., the passage from one to the next will be by means of worse conductors, and will probably leave its record in more or less destructive results.

It need scarcely be said that a lightning-conductor offers no attraction to the lightning (as was at one time supposed), but only offers to it a harmless passage if it come in contact with it. It is quite possible for a house having a conductor to be injured by lightning, since the flash may reach it at some other point; but experience has shown that the use of conductors has very greatly decreased the amount of damage.

Return-shock.—It was shown by Dr Franklin that there is really no difference between lightning and frictional electricity. We have seen that lightning can be transformed into heat and light. Can it produce any other phenomena of electricity—such, for instance, as induction? It is believed that the peculiar sensation by which we are aware of the approach of a thunderstorm is really a case of induction—that our bodies are more or less electrified by induction. After the storm has passed we no longer have this sensation, because the clouds and the earth having become both neutral, the body, freed from influence, reverts to its neutral condition.

It sometimes happens that this reversion to the normal state is so sudden that the shock is fatal. In such cases, the persons or animals *are said to be* killed, not by lightning, but by the

return-shock. The name testifies to the idea that lightning discharges were followed by a kind of rebound or return-stroke.

(12.) **Measurement of Electricity.**—Any machinery for giving evidence of the presence of electricity is called an *electroscope;* but if, in addition to this, it also measures the amount or power of the excitement, it then becomes an *electrometer.*

Electroscopes.—The attraction and repulsion of electricity furnishes a ready means of providing an electroscope. Two pith-balls suspended together repel each other, and so diverge, when any excited substance is brought near them. So do two pieces of gold-leaf, even more readily, because they have not the weight of the pith-balls to overcome. Henley's electroscope consists of a pith-ball suspended beside a vertical stem. This stem, placed at the extremity of the prime conductor of a frictional machine, gives evidence of the presence of electricity by the repulsion of the ball from the stem. The ball, in its motion from the stem, describes an arc of a circle, of which the point of suspension is the centre, and a graduated scale being placed beside it, makes the electroscope an electrometer as well, though a very imperfect one.

Fig. 85 shows Henley's electroscope as when slightly diverged by the presence of electricity. Its weakness is in the fact that a very small amount of excitement tasks the extremity of its power, and also that gravitation interferes very much with its action.

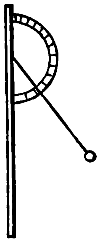


Fig. 85.

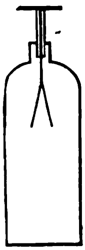


Fig. 86.

The gold-leaf electroscope, Fig. 86, is very sensitive, but too sensitive to be very useful as a means of measurement. It need not terminate in a flat plate at the top. A knob resembling that of a Leyden jar is equally useful; but the plate has the advantage of enabling the electroscope to be used also as a *condenser.*

Electrometers.—The mere attraction and repulsion of excited substances are not regular enough, and are too much affected by circumstances of the most trifling character, to allow of their being made use of as giving satisfactory evidence as to the *amount* of electricity present. More elaborate and delicate contrivances give a power of estimating this in a very accurate manner. The means of measurement is not so directly the amount of repulsion, but of force necessary to overcome that repulsion. Thus, in one electrometer, two pith-balls similarly electrified are kept together, despite their mutual repulsion, by means of a fine thread connected to a screw. The number of turns of this screw necessary to overcome the repulsion of the electricity gives a delicate and accurate measure of the amount present.

Another method is to electrify, as before, two pith-balls (en-

closed in a glass case, to prevent currents of air, dust, &c.), and to place just below them a graduated scale, so that the exact amount of repulsion can be noted and measured.

A detailed account of various electrometers will be found in the chapter on "Apparatus."

Fig. 87 shows the *torsion electrometer*, in which the amount of electric force is shown by the torsion necessary to keep *b* and *e* together, when these two pith-balls are both electrified by means of the force to be measured. Fig. 88 is *Peltier's electrometer*, which shows the amount of force present by the amount of repulsion of the movable wire *m m* by the fixed rod *d d*, when both are charged.

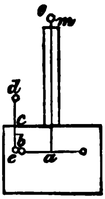


Fig. 87.

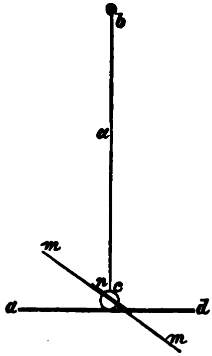


Fig. 88.

(13.) **Apparatus required to illustrate the nature of Frictional, Franklinic, or Static Electricity.**—All the apparatus should be dry and warm.

A stout stick of sealing-wax, resin, or shellac.

A rod of glass, either solid or hollow.

A piece of silk.

A piece of flannel or woollen cloth.

Two or three small sticks of sealing-wax.

A small piece of paper, say an inch square, with a sealing-wax handle. This serves to carry electricity from one body to another.

A few pith-balls, suitable because of their lightness.

A few coils of fine wire, either silver, brass, or copper.

Some pieces of linen and silk threads and twine.

With the above, all of which may be purchased for some five or six shillings, many instructive experiments may be shown. The sealing-wax or the glass, on being rubbed by the silk or the flannel, will develop electric force. The small sticks of sealing-wax may be suspended in little paper stirrups by means of threads. They will then be free to move without friction, and may be made to approach or retire when an excited rod of shellac or glass is held near. Since positive electricity repels positive and attracts negative, and *vice versâ*, the attraction or repulsion of the sealing-wax may be used as an index of the kind of electricity in any excited body brought near it. In this way a suspended stick of wax becomes a simple kind of electroscope.

The *pith-balls, and also* small pieces of paper, bits of thread,

feathers, &c., are useful to show the attractive force of electricity, since their lightness prevents this force being overcome by gravitation. The wire and threads serve for conduction and suspension.

For more systematic experiments, we want more expensive and complicated apparatus.

A plate machine, either of glass or vulcanite.

A Leyden battery, of about six jars in a case.

An electroscope, two leaves of gold-leaf enclosed in a glass case.

An electrometer: (1) *Henley's quadrant electrometer;* (2) *Coulomb's torsion electrometer;* (3) *Peltier's magnetic electrometer.*

An electrophorus, a plate of vulcanite with a metal cover.

An insulating stand, a wooden stand with a glass support.

A universal discharger, and a discharging rod.

Such a set of apparatus as here enumerated would cost from £10 to £25, or more, according to the size and quality.

(14.) **Plate Electrical Machine.** — The most convenient method of obtaining the results of frictional electricity is by means of a circular plate of glass, mounted on a spindle; and which, by being passed briskly between two pairs of horse-hair rubbers, has a continuous supply of electricity developed on its surface. In principle, this machine differs in no respect from the glass tube and silk rubber by which, in the simplest method, vitreous electricity may be obtained. Being larger, it requires to be supported in a frame. For convenience and regularity of friction, the rubbers also are mounted; and lastly, the movement, instead of being that of a rubber over the glass, is that of the glass between the rubbers. The mounting of the glass gives (in addition to the increase of power, convenience, and regularity) also the advantage of the better development of the resinous electricity, which can be obtained from the rubbers just as vitreous electricity can be from the surface of the plate.

Fig. 89 gives a diagram of a plate machine. A circular plate of smooth glass, A, is turned on its own axis by means of a handle. Two pairs of rubbers, C D, are fixed, one on either side, so that they press closely to the glass. The friction develops electricity on each part of the glass as it passes between the rubbers, and this electricity is taken from the plate by the conductor E (a tube of brass), which presents to the surface of the glass small points, *r r*, which, as it were, clean the glass as it passes them; so that all the electricity developed by the rubbers C is taken away by the points *r*, leaving the glass surface free to develop another supply, by passing between the rubbers D, for the points *r*. In their passage from C to E and from D to E, the electrified portions of the glass are covered by oilskin to prevent the escape of the electricity, which requires a slight interval of time after passing the rubbers for the full development of the force.

There being no edges or points at which it can escape, the electricity passes along the arms of the conductor E, and is collected

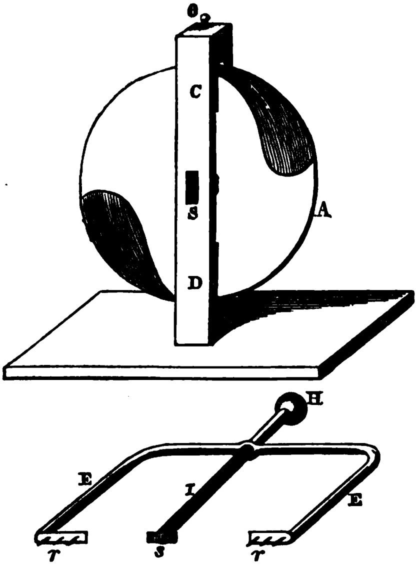


Fig. 89.

on the knob H, which is the most convenient part from which to obtain it for any required purpose. The arm, I, by which the conductor is mounted, is of glass, so that the conductor is insulated, and the electricity can only escape by some other conductor being presented to it, or by slow dissipation in the surrounding air. S is a kind of niche in which the arm I fits at *s*. The revolutions of the glass plate are effected by means of a handle, and the centre of the plate serves as a means of insulating this handle, since the electricity is only developed on the part of the glass subjected to friction.

The electricity developed on the glass and carried away by the conductor is, of course, vitreous or positive; but an equal quantity of resinous or negative electricity is developed on the surfaces of the rubbers, and can be collected by attaching a conductor to the rubbers. In ordinary working it passes away along the framework to the ground. A resinous plate gives negative electricity.

It must be carefully borne in mind that there is no specialty about the "electrical machine," other than that it is the most

convenient arrangement by which glass can be subjected to friction, and the developed electricity collected. The principle is essentially the same as when an ordinary glass held in one hand is rubbed by a silk handkerchief held in the other.

In describing experiments and illustrations it will be sufficient to speak of the knob, H, of the conductor. It must be understood that in such cases it is implied that a plate machine (such as here described) is in working order, and that the knob, H, is charged with vitreous or positive electricity therefrom.

I spoke just now of the points of the conductor cleaning the electricity off the surface of the plate of glass as rapidly as it was developed by friction, but another theory describes the operation in another manner. According to this, the positive electricity of the glass decomposes the electricity of the conductor, and draws from the conductor to the glass the negative electricity of the conductor, leaving it charged only with its own positive electricity. Thus (if P and N express respectively positive and negative electricity), when I begin to turn the handle, the glass and conductor are both in electrical equilibrium—*i.e.*, each has P and N in equal quantities. By friction I decompose the electricity of the glass, N escapes to the earth by means of the framework of the stand, with which the rubbers are in contact, and P, left free on the glass, attracts N from the conductor. The glass is then restored to equilibrium, while the conductor has only P.

It will be seen that either theory seems sufficient to explain the fact, that the conductor becomes charged with positive electricity whenever the glass is subjected to friction; and that the amount developed and collected on the knob of the conductors increases with the amount of friction.

(15.) **The Leyden Jar.**—I take a plate of glass, and coat each side with a piece of tinfoil, taking care that there shall be a rim of uncovered glass right round each piece of foil, so that the two pieces cannot communicate at the edge of the glass. By placing either side in connection with the conductor of a plate machine, I charge that side with positive electricity, and on testing the other side I find it to be charged with negative electricity. Conversely, if I charge one side with N, I find the other side to be P. These two charges—one N and the other P—will naturally attract each other; and if I hold the glass between my hands—*i.e.*, place one hand on the foil charged P, and the other on the side charged N—my body will serve as a conductor. I shall receive an electric shock (depending for its force upon the quantity of electricity developed), and the coated plate of glass will be restored to its original condition.

If I make the glass into a bottle, and line the lower portion of the inside and cover the lower portion of the outside with tinfoil, the upper uncovered part of the bottle will prevent any communication between the lining and the covering. If now I charge the

inside P or N, I find the outside to be charged N or P; conversely, if I charge the outside either P or N, I find the inside to be charged N or P. Then, as before, if I connect the outside and inside by any conductor, I discharge the bottle, and it is restored to its original neutral condition.

For convenience of charging, and of connection with other apparatus, a **discharging rod** is often used, consisting of a small pair of tongs, of which the handle is of glass, and the legs of brass, terminating in rounded knobs. The legs may be opened at will, and if one knob be placed on the inside of a Leyden jar, and the other knob on the outside, the jar is at once "discharged." The glass handle prevents the escape of the force.

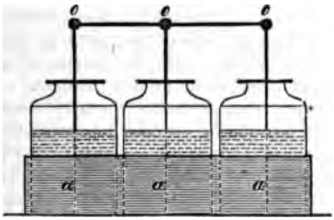


Fig. 90.

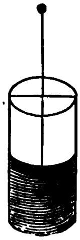


Fig. 91.

If I desire to accumulate more electric force than one jar will retain, I make a battery of such jars (therefore called a Leyden battery) by putting together any number, usually six, nine, or even twelve, in a small case. The jars are grouped together by being placed side by side in a plain wooden case just large enough to hold them. The bottom of the box is covered with a piece of tinfoil, which is thus in contact with the foil on the outside of the jars, and by this the outside coverings of all the jars become, electrically, but one, and the battery is practically one large jar.

It is necessary that all the inside coatings should be also in like manner connected, and this is done by means of pieces of brass wire. Each jar has a wooden lid—*i.e.*, a plain circular piece of wood, resting on the top of the jar. Through the centre of this passes a piece of brass wire, *a*, terminating above in a brass knob, and below in a chain that reaches to the bottom of the jar, and a few of the links of which lie on the tinfoil with which it is lined, and thus effectually secure the metallic connection of the knob above with the inner coating. This inner coating may thus be said to rise up, in the form of a knob, above the top of the jar, for the convenience of connection with other apparatus.

These knobs have small holes, *o*, in their sides, and by inserting a piece of brass wire into these holes, any two jars may be, electrically, made into one; and any number of jars be likewise connected so as *to become, so far* as the inner coatings are concerned,

but one large jar. So that when any number of jars are placed in a box, their outer coatings being connected by the tinfoil in the bottom of the box, and their inner coatings by the brass rods reaching from knob to knob, we have a Leyden battery. Any one of these jars being placed in connection with the conductor of a machine, the electric force thus received by it is spread over the surfaces of the whole number of jars, and the charge they can retain is much greater than one jar could keep, because of the great increase of surface thus offered.

If I charge the inner coatings, I bring one of the knobs near a conductor. It is necessary to put the outside of the jars in contact with the earth; this is usually done by letting a small chain hang over the edge of the box, partly inside (in contact with the tin-foil), and partly outside (in contact with the ground). But I can just as easily charge the outside of the jars by placing the inner coatings in contact with the earth, by means of a chain or wire reaching from one of the knobs to the ground. It will be noticed that the wooden box is of no service, except as serving to connect all the outer coatings (which might be easily done otherwise), and to keep the jars together, for convenience of moving, &c. In large batteries, a number of small gas jets are kept alight under the case containing the jars, for the purpose of keeping them warm. It is essential that all the apparatus for frictional electricity should be dry and warm.

(16.) **Electroscope.**—This is usually two leaves of gold-leaf attached to the end of a brass rod, so that they are free to move to and fro. To prevent their being moved by currents of air, they are commonly enclosed in a glass case. If I take an ordinary clear glass bottle, make a hole in the cork, and pass through this a piece of brass wire, terminating above in a small flat plate of metal, I have all that is really essential in the construction of an electrometer when I have fastened to the lower end of the wire the two pieces of gold-leaf. The leaf is usually sold in small leaves, somewhat like a book. I put two such leaves together and cut a narrow strip off each with a sharp knife. I breathe on one end of the pieces so cut off, and press them together, after putting between them the end of the wire, which should be flattened so as to receive them. They will adhere quite firmly; and if the cork, having the wire and two gold-leaves, be now put in the mouth of the bottle, the electroscope is complete. The two leaves hang down side by side, looking like one, until some electric force is applied to the metal cap outside, which is in metallic communication with the leaves. Any force thus applied to the cap instantly extends through the wire to the leaves, and they at once diverge, each repelling the other. The leaves are very delicate, and are easily torn. If the force applied to the cap be too strong, the leaves will repel each other so violently as to come into contact with the glass side of the case. This will give trouble, for

the gold-leaf is almost sure to adhere to the glass; and if I turn the wire round so as to pull it away, it is quite as likely to tear it in half. To prevent this, two narrow strips of tinfoil are placed on the sides of the glass inside, reaching from near the top to the bottom. Whenever the leaves repel each other so strongly as to come in contact with the glass, they touch these pieces of tinfoil, which, being in contact with the wooden bottom which a properly-made electroscope has, and therefore in connection with the earth (supposing the apparatus not to be insulated), the electric force is immediately carried off, and the leaves, being discharged, resume their original position by reason of their weight. A pith-ball suspended from a glass rod is a simple form of electroscope.

(17.) **Electrometers.**—The electroscope gives evidence of the presence of electric force, but only in a very vague manner enables us to judge of its amount or intensity. If we want to compare any two such forces, or to compare any one such force with any fixed standard, we require an electrometer. Of these the simplest is Henley's quadrant electrometer, consisting of a small upright wooden or metal column, fixed in a small stand, and having suspended from its upper end a still smaller slip of wood, or thread, at the end of which is a pith-ball. If I place such an instrument on the conductor of a machine, and excite it, the small arm carrying the pith-ball is at once repelled from the upright stem, and the degree of this repulsion, measured by a small graduated arc, marks the comparative degree of electric force present. But this is a very simple and not very trustworthy instrument. Fig. 85.

The *torsion electrometer* is a much more accurate instrument, and consists essentially of a very light shellac rod a, terminating in a pith-ball b, and suspended by a fine wire or thread from the top of a small glass case. It is thus free to move without friction, and the pith-ball, when electrified, is insulated by the shellac rod being a non-conductor. The rod and ball hang horizontally across the glass case, and a second rod c, also terminating in a pith-ball e, passes through a small opening in the top, so that the two pith-balls are in contact. This second rod and ball are removable and replaceable by means of a handle d projecting outside the case. I desire to measure, by means of this instrument, the intensity of the electric force on the conductor of a machine, a Leyden jar, or any other body. I take out the movable ball e, place it in contact with the electrified body (by which contact it becomes itself excited), then replace it in the electrometer. The ball in the instrument, b, is electrified by contact with the ball e, and is repelled by it. In moving away it turns round the thread by which it is suspended, and this is turned by the handle o, on

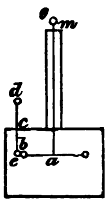


Fig. 92.

the graduated plate *m*, at the top of the instrument. The two pith-balls may be brought together again by turning the handle *o*, but the thread will be twisted by the opposite forces—one applied to the handle tending to turn it one way, and another, the repulsion of the pith-balls, tending to turn it the other. Still, by turning the handle *o*, the two balls may be forced together, notwithstanding their mutual repulsion; and the amount of turning required to effect this is proportionate to the electric force on the balls, and therefore to that on the conductor or jar that has to be measured. The method of measurement, not by the amount of repulsion, but by the amount of turning required to overcome the repulsion, explains the name of torsion electrometer given to this instrument.

Peltier's electrometer is essentially the same as the one just described, but can be more easily charged and discharged. An upright brass stem *a* terminates above in a knob *b*, and below in a ring *c*, and two arms *d*. A very light wire *m*, and also a small magnet *n*, move freely upon a point fixed at the bottom of the ring *c*. The position of the arms *d* depends upon that of the stem *a* to which they are fixed; but the position of *m* depends on the magnetic meridian, the magnet *n* pointing nearly N. and S. By turning the whole apparatus round as far as necessary, the two arms *d* and the wire *m* are brought together. If now any charge of electric force be communicated to the knob *b*, it is at once diffused over the whole of the stem and arms. The arms *d* cannot move, being in rigid connection with the stem *a*, but the wire *m* moves freely on the pivot, being kept in its position only by the magnetism of the needle, which, though strong enough to determine the position of *m* when free from other constraint, is too weak to offer any practical resistance to any active force, such as the mutual repulsion of the bars *d* and *m* when both are similarly electrified. Consequently when they are so excited, by the application of any electric force to *b*, the movable bar *m* is at once repelled from the arms *d*. The amount of this repulsion, which can be known by reference to a graduated circle, shows comparatively the amount of force present. The whole apparatus is usually enclosed in a glass case.

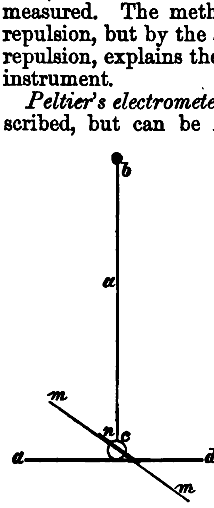


Fig. 93.

Another and very accurate method of measuring the amount of electricity produced in any given time, or by any given amount of labour, is to use a **unit jar.** This is a small Leyden jar, having at a fixed distance from its knob a discharging rod connected with the outer coating. If this small jar be connected with the machine, it will be discharged whenever the amount of

force accumulated is sufficient to cross the distance at which the discharging rod is fixed. The number of discharges will be a measure of the whole amount of force that has been developed.

(18.) **Electrophorus.**—This consists of a small circular disc *a* of some non-conducting material (glass or vulcanite usually), resting on a larger disc of brass *b*, and having a metal disc *c* of smaller size, with a glass handle to fit on it. The disc of vulcanite can be excited by beating it with a piece of flannel or skin, and being insulated, will remain excited, even for days, if the air be dry. The cover *c*, when placed on the excited disc *a*, becomes also excited, but being also insulated will remain so. It may even be carried about by means of the glass handle, and will still retain the force derived from contact with the disc of vulcanite, if certain precautions be taken. There is a striking resemblance between the action of the electrophorus, and the example of inductive action explained at page 156.

Fig. 94 shows an electrophorus with the cover. This cover is really the *electro-phorus* or electric carrier, since it conveys away from the excited plate a small amount of force every time it is brought into contact and removed. A small plate of vulcanite, some 4 inches across, has retained some traces of excitement for ten days, when placed on the marble mantelpiece in my room. The air being warm and dry has prevented the escape of the force.

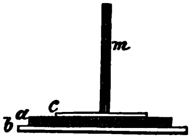


Fig. 94.

(19.) **Universal Discharger.**—This is a convenient piece of apparatus for subjecting small objects to the action of a current of electric force. It consists essentially of a small table of bone or ivory, and two metal rods with glass handles. Usually the two metal rods terminate in knobs *a*, and are mounted on glass stands *b*, one on either side the table *c*. Two ball-and-socket joints, *d*, enable these rods to be moved in any direction by the glass handles, and the two knobs can be brought together on the table *c*.

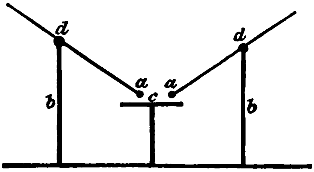


Fig. 95.

Let it be required to pass a current of electricity through a piece of fine wire. I lay it on the table *c*, and connecting by wires one of the brass rods *a* with the conductor of a machine, and the other with the earth, I bring them both in contact with the piece of wire on the table, and it is at once made part of the conducting circuit. Or I connect one rod with the outer coating of a Leyden jar, and the other with the inner coating, and as

before, the wire, reaching from one knob to the other, forms part of the circuit, and the electric force passes through.

The Condenser.—If by the side of a wide but shallow pond I dig a deep hole and connect them, the water will be drawn off to fill the hole at but a small loss of depth to the pond. In the same way a deep and narrow well will contain much more water than a shallow one. Similarly, if by any means I can increase the power of a body to retain electricity on its surface, it will draw to itself a large part of the force collected on any other surface with which it may be brought in contact. In fig. 96 a glass rod excited drives part of the electricity down to the gold-leaves, which are positive, while the cap is negative. Here the cap is in equilibrium with less than its normal amount, because the extra amount in the rod stands instead of it. If the rod had been — the cap would have been + *i.e.* would have contained more than its normal amount. So that I am able by holding near the cap a + or — body to enable it to be in equilibrium with either less or more than its natural amount; that is, it is either a condenser or the reverse.

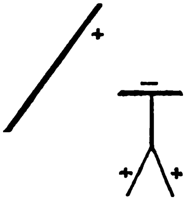


Fig. 96.

If I desire to charge a Leyden jar, I must connect the one side with the conductor of the machine and the other side with the earth, or some other large conducting substance. Then if I charge one side positively, the other becomes negative; if I charge one side negatively, the other becomes positive. That is, as before, the second side becomes a condenser or the reverse, able to contain more or less than its proper amount.

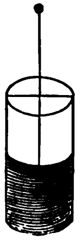


Fig. 97.

In fig. 98 are three Leyden jars on a stand, M, which is of glass. If I take away the wires a and b, then only A will be charged by the conductor D, and for this to be done I must connect the outside with the ground. When A is charged, if I connect the two knobs of A and B by a wire, might I not reasonably expect that B would be charged by conduction? But no such result would follow, because really the inner coating of A would be a condenser or the reverse, according as its electricity is positive or negative. If it be positive, it will not impart any of its force to B; if it be negative, it will not draw any from B. I assume here, for clearness of illustration, the truth of the single-fluid theory. But it is certain that electric force may be, as it were, rendered latent by a condensing apparatus. Compare the action of a condenser with the phenomena of latent heat.

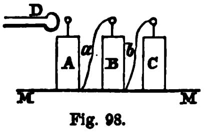


Fig. 98.

So in the case of the electrophorus: if the plate *a* be of vulcanite, and therefore negative, the upper plate *c* becomes a condenser, and will contain more than its normal amount of electric force. But if the plate *a* be of glass, then the upper plate *c* is the reverse of a condenser, and will not contain its proper amount if any road be open for the passage of the surplus force.

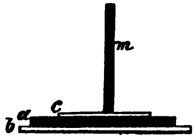


Fig. 99.

To what practical use can this be put? Why should we desire to condense electric force? The purpose for which Volta invented the condenser was the detection of very weak currents. If a large surface be charged with a very small amount of electricity, ordinary means of detection will fail; but if I connect with it a condenser—*i.e.*, a body capable of containing more than its normal amount, this will draw to its surface a greater part of the force than it otherwise would, and so render the force capable of measurement. A familiar example is offered by an ordinary dinner-dish having a depression at one end, so that the gravy may be collected there for the more convenient use of the spoon.

Specific capacity for induction.—I have shown that two metal plates near each other, with the intervening air, are really a Leyden jar in everything but shape. If one such plate be electrified, the other is also affected by induction. If now I interpose between these plates a sheet of glass, I bring the resemblance to a Leyden jar still nearer; but I have done more than this. I have altered the amount of inductive power on the second plate. It is nearly twice as great passing through the glass. By substituting for the glass a plate of sulphur I increase the inductive power still more.

If I have a number of Leyden jars, one of resin, one of wax, a third of glass, a fourth of sulphur, I find the induction to be greatest when I use the sulphur jar, and least when only air is between the plates. Thus, for 10 units of power condensed when I use air, I get 17 when I use resin, 18 for wax, 19 for glass, and 22 for sulphur.

SUMMARY.

SEALING-WAX rubbed with flannel, and glass rubbed with silk, has the power of attracting light substances, which are after a time repelled. This same power is possessed in a less degree by all substances; but in many only to a very small extent. The name of **electricity** is given to this power. Page 132.

The chief **effects of electricity** are *attraction, heat, light, chemical action, magnetism.* Page 135.

The chief **sources of electricity** are *friction, pressure, cleavage, heat.* Page 138.

The electricity developed on one body by friction may be *conducted* to another, if they are connected by any substance along which the electricity can travel. Page 139.

Substances along which electricity can travel are called **conductors**: others we call **non-conductors.** Page 139.

Electricity, when sufficiently accumulated, will assume the form of a spark, called the **electric spark.** Page 141.

Electricity may be regarded as a "mode of heat," and is probably an effect of motion. Page 145.

Electricity will pass through the human body, and its passage is marked by a series of slight shocks at the joints. Page 146.

Electricity is a **surface effect** only. Page 147.

Electricity will escape readily from *points;* but only with difficulty from rounded bodies. Page 149.

Electricity will pass across a non-conductor on its way from one conductor to another. Page 149.

The **velocity** of electricity, through a good conductor, is 280,000 miles per second. Page 154.

An excited glass rod held near an electroscope will cause it to be effected without contact, but only while the rod is near it. This effect is called **induction.** Page 156.

Lightning is ordinary electric light on a large scale. Page 161.

The damage said to be done by lightning is really caused by the conversion of the electricity into heat. Page 162.

Apparatus for the detection of electricity are called **electroscopes**; those for its measurement are **electrometers.** Page 164.

For the detection of very small amounts a **condenser** is used. Page 174.

GALVANISM.

Galvanism
Voltaic Electricity
Chemical Electricity
Dynamical Electricity } These terms are synonymous.

(1.) **Introduction.**—I take a piece of zinc, about nine inches by six, and one-eighth of an inch or more in thickness. This I roll into a cylinder, and stand in a glass vessel of similar shape. Inside the zinc I place a porous earthenware jar, and inside this a bar of carbon, about an inch thick each way, and long enough to stand about an inch above the zinc. There is about a quarter of an inch of space all round between the zinc and the outer glass, and also between the zinc and the inner jar, and as much or more between the jar and the carbon.

The zinc and the carbon are the elements of the galvanic battery—the glass jar is to contain the one, and the earthenware jar the other. I mix sulphuric acid with about seven times its volume of water, and with the mixture nearly fill the glass jar containing the zinc. As soon as I connect in any way the zinc and the carbon, the galvanic action will commence, and will flow from the carbon to the zinc.

The action of the battery will be this: The water in contact with the zinc will be decomposed—*i.e.*, separated into its elements, hydrogen and oxygen. The oxygen will unite with the zinc, while hydrogen will be given off at the surface of the carbon. The oxide of zinc, formed by the union of zinc and oxygen, will be dissolved by the dilute acid in the glass vessel; but the hydrogen is given off on the surface of the carbon, though the water is decomposed by the zinc. This is because the water between the two is decomposed, particle by particle, and recomposed. Thus, supposing there be ten atoms of water between the carbon and the zinc, then the atom nearest the zinc is decomposed, the oxygen uniting with the zinc, the hydrogen being free. The current de-

composes the next atom, and its oxygen unites with the hydrogen of the first atom; and so on, until the hydrogen of the last atom—that nearest the carbon—is alone free, and, having nothing to combine with, is given off.

Fig. 100 shows the supposed arrangement of the atoms of water before decomposition; and, in the second row, the arrangement afterwards with the extreme atoms of O and H free.

$\boxed{OH}\ \boxed{OH}\ \boxed{OH}\ \boxed{OH}\ \boxed{OH}\ \boxed{OH}\ \boxed{OH}\ \boxed{OH}$

$\boxed{O}\ \boxed{HO}\ \boxed{HO}\ \boxed{HO}\ \boxed{HO}\ \boxed{HO}\ \boxed{HO}\ \boxed{HO}\ \boxed{H}$

Fig. 100.

The zinc and carbon must be united by a wire, or some other conductor, before the current will be developed; and even when this is done it will be very feeble, owing to the hydrogen set free filling the pores of the earthen jar. This, however, is easily remedied by pouring a little strong nitric acid into the inner jar. The hydrogen combines with some of the oxygen of the acid to form water, and the acid becomes nitrous acid. Thus $NO_5 + H$ becomes $NO_4 + H_2O$.

The zinc in the glass vessel, the carbon in the earthen vessel, and the sulphuric acid (diluted with about seven times its volume of water), form the essential elements of galvanic action—the nitric acid (not diluted) being necessary only for the absorption of the hydrogen set free.

Any number of these cells, or units of galvanic action, may be united to make a more powerful current, and the compound cell or battery will act as one cell of greater strength. The zinc of each cell must be connected with the carbon of the next. Thus the current will pass from the carbon of the end cell through the acid to the zinc of the same cell, thence by the connecting wire to the carbon of the next, thence to the zinc, and so on to the end. From each cell a separate current is generated; all of them flowing in the same direction, to the zinc of the cell at the other end. The two wires, one from either end, may be joined, in which case the current is at once generated, but any piece of apparatus or metal, or any other substance, may be made a part of the path of the current. Thus, if I desire to measure the strength of the current, I place a **galvanometer** in the circuit by fastening the wire from the zinc end of the battery to one side of it, and the wire from the carbon to the other. The current then passes from the carbon through the galvanometer to the zinc.

If I wish to decompose water, I connect the apparatus for the electrolysis with the battery in the same manner as I did the galvanometer; and generally, in all apparatus intended for operation by galvanism, it will be found that two small screws are arranged, one on either side, so that by the two wires from the battery being screwed in, the current passes through as required. In describing the practical application of galvanism, such a

phrase as "passing a current through," or "connecting with a battery," will mean this completion of the circuit by a wire from each end of the battery being connected with the particular apparatus described.

This action of a galvanic current may be very simply illustrated by a galvanometer and two pieces of copper and zinc. A galvanometer is an index of galvanic strength, consisting of a needle, which, by its deflection to the right or left, shows that a current is passing through the wire that is inside the galvanometer. The wire is usually inside a small wooden case; while the needle is in front, protected by a glass plate, through which its movements are visible. At each side is a small screw for fastening wires from a battery, so that the current shall pass through the coil of wire inside and deflect the needle.

Fig. 101 shows the front and back of a galvanometer. In the front is seen only a vertical needle working on a pivot. Behind is seen a second needle working on the same pivot. In both figures, two screws, *o o*, serve to fasten the wires from the battery to. Within a continuous wire goes from one screw to the other, being in its passage folded to and fro several times on either side of the inner needle. Two needles so joined together are called an *astatic needle*.

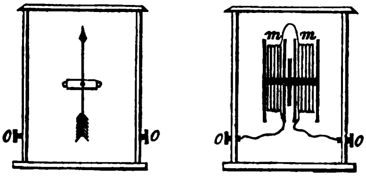


Fig. 101.

Take a thin piece of zinc about two inches by one, and a piece of copper of equal size, solder a short copper wire to each, and fasten the ends into the screw-holes of the galvanometer. Turn the wires so that the two pieces of metal come together in front of the galvanometer, and dip them together into a saucer of water diluted with a little sulphuric acid. Galvanic action will immediately commence, of which evidence will be given by the needle moving a little towards the side to which the wire from the zinc is attached. If the copper and zinc be changed in place, the needle will change its deflection, always bending towards the zinc. The zinc, assisted by the acid, will decompose the water in contact with it, and hydrogen will be liberated at the surface of the copper, oxygen uniting with the zinc to form oxide of zinc, which will again unite with the sulphuric acid to form sulphate of zinc, which will be dissolved in the water.

The zinc will decompose the water without the copper being present, but this will be merely a case of chemical action, without any electrical action being evident. If the zinc and copper be put together in the acidulated water, and the wires joined, a current will be at once generated, the two metals and the acid water being all that are necessary to produce it. The galvan-

ometer does no more than give evidence that a current is so generated.

(2.) **Chemical Origin of Galvanic Force.**—Chemical action requires absolute contact. Gunpowder may be placed in the interior of a gas-flame of large size without any danger of an explosion, although entirely shut in by the flame. A jar of hydrogen will burn, with a flame, only at the points of contact with the oxygen of the air, the lower portion of the hydrogen being unaffected until it come into actual contact. So a plate of bright zinc when in water is acted upon chemically, until the surface be covered with a thin coating, which prevents the actual contact of the metal and acid. Thus, if I put zinc in water I have $Zn + H_2O$, but this becomes $ZnO + H_2$—*i.e.*, the oxygen of the water combines with the outer particles of the zinc and forms zincic oxide. This being insoluble in water, remains, by the force of adhesion, on the surface of the still pure zinc, and prevents further oxidation, because the pure zinc is kept from contact with the water.

If now I use, instead of water, a solution of sulphuric acid, the zincic oxide, as fast as made, is converted into sulphate of zinc, which is soluble in water; and in this case the decomposition of the water by the zinc is not stayed as before, because the oxide is converted into sulphate, and dissolved in the water as rapidly as it is formed.

In each case the hydrogen liberated by the decomposition of the water is evolved from the surface, owing to its lightness and insolubility. But if the zinc be amalgamated with mercury, the oxidation will, after a time, be stayed, even though the oxide be converted into sulphate by acid. And this will be found to be because the hydrogen, instead of escaping from the surface of the water, is attracted by, and adheres to, the surface of the amalgamated zinc. If these bubbles of gas be cleaned off, the chemical action will proceed as before.

But we need not remove these bubbles by hand. A plate of some other metal, say platinum, introduced into the liquid will remove them, *if the two metals be in contact*, but not otherwise. The hydrogen will now be evolved from the surface of the second plate, which will be itself but little (if at all) affected by the acid or the water.

It would appear as if the hydrogen passed from the zinc to the platinum, and was there evolved. But this is improbable, since there is no evidence of its passage. The theory that is usually accepted is, that the atoms of water between the two plates are all *decomposed*, and their constituents *recomposed*, leaving atoms of oxygen free at the zinc plate (with which they combine), and atoms of hydrogen free at the platinum plate, from which they are given off.

The plates must be in contact for this action to take place, but

this contact need not be immediate. It may be made by means of wires, and these wires may be of indefinite length, in which case we get the ordinary phenomenon of the electric telegraph, in which the connecting wires are miles in length.

To recapitulate these phenomena,—

A plate of zinc is placed in water.	*Water is decomposed and the zinc covered with oxide of zinc, which prevents further action.*
Sulphuric acid is placed in the water.	*The oxide is converted into sulphate of zinc (which the water dissolves), and the oxidation is not arrested as before.*
The zinc plate is amalgamated with mercury to prevent "local action."	*The zinc is, at first, oxidised as before, but the action is arrested by the adhesion of hydrogen to its surface.*
Another metal plate (not zinc) is introduced in contact with the zinc.	*The hydrogen is evolved from the surface of the second plate, and the oxidation of the zinc is continuous.*
The connection of the two plates is made by means of wires.	*The same result.*
These wires are of indefinite length.	*This would be the nucleus of an electric telegraph.*

(3.) **Various Forms of Galvanic Batteries.**—I have mentioned that the hydrogen set free from the decomposition of water by means of zinc adheres to the surface of the zinc when it is amalgamated, or to the surface of the copper, platinum, or other negative plate. This adhesion interferes very materially with the development of the current, and many expedients have been devised to prevent it. The general principle of most of these is to bring into contact with the hydrogen evolved some substance, simple or compound, that shall absorb it as rapidly as it is evolved, so as to prevent its interference with the development or progress of the current.

Grove's Battery.—One of these methods is the battery of Mr Grove. In this the evolved hydrogen is brought into contact with nitric acid, which is reduced to nitrous acid by the abstraction of some of its oxygen, taken from it by the free hydrogen, so that the mixture of nitric acid and hydrogen produces nitrous acid and water. This forms a very effective battery, but also an expensive one, owing to the costliness of platinum. Copper plates would be affected by the nitric acid, so that platinum is substituted as not being soluble in the acid necessary to absorb the hydrogen. A "Grove's nitric-acid cell," therefore, consists of two earthenware cells, one within the other, the lesser being unglazed and porous. In these inner cells are plates of zinc in dilute sulphuric acid; in the outer ones, plates of platinum in strong nitric acid, or a mixture of nitric and sulphuric acids. The current passes from the zinc to the platinum, the zinc being oxidised, and the hydrogen thus liberated absorbed by the nitric acid, which is reduced to nitrous acid. Any number of *cells* make a *battery*.

Fig. 103 shows a section of a Grove's cell, *a* being the zinc plate, and *c* the platinum plate enclosing it. The flange *o* of the platinum is for connection with the next cell. The nitric acid, in which the platinum plate is immersed, is shown by lines thus, \ and the sulphuric acid in the inner cell by lines /. Fig. 102 shows the same cell as seen from above, the lettering and shading being the same.

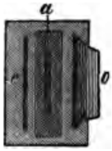


Fig. 102.

Fig. 103.

Bunsen's Battery. — To avoid the expense of platinum, M. Bunsen arranged a battery in which zinc, as before, is the positive element, but the negative is carbon, a substance unaffected by nitric acid. The only difference between a "Grove" and a "Bunsen" is the substitution of a carbon cylinder for the platinum plate. The general structure, action, and results are the same in both. The carbon is outside and the zinc inside, because it is an advantage in point of power to have the positive element within the negative, for the same reason that a wire conducts the better for being thick. If the currents proceed from each point of an outer circle to the centre they must get crowded together, interfere with, and partially destroy each other; while if they proceed from the centre outward, they have more and more room for their action. Therefore it is greatly preferable to have the positive element, from which the currents proceed, in the centre, and the negative one outside it.

Fig. 105 shows a Bunsen's cell. The rod or bar of zinc *a* is in the centre, surrounded by the cylinder of carbon *b*. Fig. 104 shows the same cell from above. A Grove's cell is square, a Bunsen's is circular.

Fig. 104.

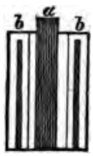


Fig. 105.

But the same objection that exists against the platinum as an element—*i.e.*, the expense—also exists against the use of carbon when made into hollow cylinders. Carbon itself is not expensive, but to make it into cylinders is difficult and costly, and it is found in practice that it is really cheaper to make two cells having a bar of carbon inside a cylinder of zinc, than one having a cylinder of zinc within a cylinder of carbon; in addition to which, the hollow cylinders of carbon are much more liable to be fractured than the solid bars. This has led to the modification of Bunsen's battery in common use in England, which consists of solid bars of compressed carbon as the negative element, and cylinders of amalgamated zinc as the positive. In all other respects the arrangements are exactly as the Bunsen battery, which is itself but a modification of the Grove. If in figs. 104 and 105 we suppose *a*

to be the carbon and *b* the zinc, they will show the English form of the Bunsen battery. I can testify to the strength of a ten-cell battery of this kind that I have had in use for two years.

Daniell's Battery. — Another method of getting rid of the hydrogen is to bring into contact with it sulphate of copper. According to one theory of the composition of sulphate of copper, it is made up of sulphuric acid and oxide of copper, and the hydrogen, assisted by the electro-motive force of the current, is supposed to decompose the sulphate, to unite with the oxygen of the oxide, setting free the copper and the sulphuric acid. The latter remains in solution in the water, while the metallic copper adheres to the negative plate, which in this battery is copper, and the result of this adhesion is simply to increase the thickness of the plate without decreasing its powers as an element of the battery. This theory of the composition of sulphate of copper has been somewhat modified, but the change refers rather to the arrangement of its constituents than to their quantity, so that the decomposition, the union of oxygen with the free hydrogen, and the deposition of copper, is equally possible and probable with the modern theory. In this way the hydrogen is got rid of, and the negative plate of the battery remains in good working order. This has procured for this arrangement the name of "Daniell's constant battery."

The usual arrangement of a "Daniell's battery" consists of a glass vessel to contain a copper cylinder, inside of which is placed a porous vessel to hold the amalgamated zinc. This inner vessel is filled with dilute sulphuric acid, in which the zinc is placed, while the copper is immersed in a solution of sulphate of copper, which is decomposed as already described. Fig. 107 shows a cell of this kind. *Cu* is the copper vessel, and *Zn* the zinc. Fig. 106 shows this from above.

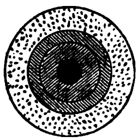


Fig. 106.

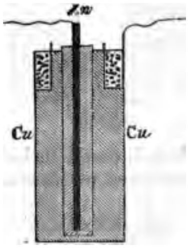


Fig. 107.

To provide for the continuous action of the battery, it is necessary to have a continual supply of sulphate of copper, and this is arranged for by making a kind of hollow rim to the copper plate, which is filled with solid copper sulphate. As the solution is deprived of its copper by the action of the battery, these solid crystals are dissolved, and thus a constant supply is furnished. The crystals are dissolved and decomposed, the copper being deposited on the surface of the negative plate. These are shown in fig. 107 at the top, and in fig. 106 as forming an outer circle.

This battery has also the advantage of having the positive element within the negative, so that the currents proceed outward, and have thus more room; and if both plates be in the same fluid (as they may be), the sulphuric acid derived from the decomposition of the sulphate is available for the conversion of the oxide of zinc into sulphate of zinc.

Smee's Battery.—A third method of providing for the hydrogen set free by the formation of oxide of zinc is to roughen the surface of the negative plate, so that from the points so made the gas is given off. It adheres to the copper or platinum because the surface is smooth. In the Smee battery the negative plates are of silver, and the surface of this is roughened by depositing on it platinum in powder. This forms a series of fine points, which are favourable to the escape of the hydrogen from the plate.

The arrangement in this battery is to have a single flat plate of silver placed between a double plate of amalgamated zinc, so that each surface of the silver or negative plate has opposed to it a zinc or positive plate. Hydrogen adheres to smooth surfaces, but escapes readily from the points of roughened plates; but though it is thus, in the Smee battery, prevented from interfering with the working of the battery, it is given off as gas, while in the Daniell's battery it is altogether absorbed. In the arrangement of the Smee battery the current proceeds inwards from the zinc to the platinised silver, and this is a disadvantage.

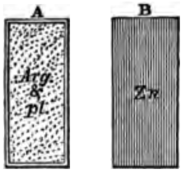


Fig. 108.

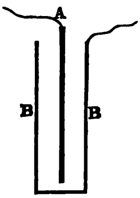


Fig. 109.

Fig. 109 shows the zinc plate B doubled, having within it the silver plate A covered with powdered platinum. Fig. 108 shows the plates separately.

(4.) **Effects of Galvanic Currents.**—The current of a galvanic battery will decompose compound substances, will affect the direction of magnetic needles, and will raise the temperature of any substance through which it passes if its progress be arrested.

(A.) *Chemical Analysis.* — I place two wires in connection with a voltaic battery, and let them terminate in small platinum plates. The wires may be of any conducting substance, as copper, but should terminate in platinum, which is not subject to much chemical action. I put these plates in a solution of the compound to be decomposed, and (if the current be of sufficient power) the constituents of the compound will divide into two groups, one of which will go to the positive and one to the negative pole of the battery. If the compound have but two elements, one will go to each pole. Thus, if I decompose hydrochloric acid, which is a compound of hydrogen and chlorine, the chlorine will be found

at the positive pole, and the hydrogen at the negative—that is, chlorine gas will rise from the positive pole, and hydrogen from the negative, both being obtained by the decomposition of the acid. It it be a compound of more than two elements, I get a simpler compound at each pole. Thus, from the decomposition of sulphate of soda, I get at one pole sulphuric acid, at the other soda —*i.e.*, the two compounds of which sulphate of soda is composed. Again, common salt, which is a compound of chlorine and sodium, will give chlorine at the positive pole and sodium at the negative, but the sodium will be converted by the water into soda; while sulphate of ammonia will give the compound sulphuric acid at the positive pole and the compound ammonia at the negative. Sulphate of copper, in like manner, gives sulphuric acid and copper.

Fig. 110 shows a simple apparatus for electrolysis, consisting of a V tube fixed to an iron stand, sufficiently heavy to keep it steady. *o o* are the two platinum plates at the ends of the wires *s s*, to the other ends of which are fastened the + and — wires from the battery.

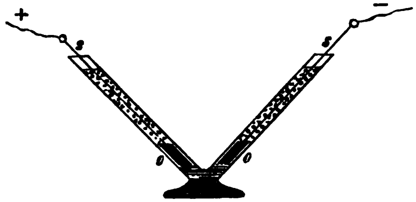


Fig. 110.

The bubbles of gas are shown as rising in the tubes from the liquid at the lower part of the apparatus.

(i.) The compound to be decomposed must be made part of the circuit—*i.e.*, the current must be made to pass through it.

(ii.) The compound must be in a liquid state. A solid either conducts the current or breaks it (according as it is or is not a conducting substance), but is not chemically decomposed by it.

(iii.) The compound must be of a conducting and a non-conducting substance: otherwise the current is simply conducted or totally arrested.

(iv.) The conducting substances go to the negative pole; the non-conducting to the positive.

(v.) The greater the amount of the electricity, the greater the amount of the compound decomposed.

EXAMPLES OF ELECTROLYSIS.

1. **Potassic iodide** (*iodide of potassium*).
   Negative pole, potash.
   Positive pole, iodine.
2. **Cupric sulphate** (*sulphate of copper*).
   N. p., copper.
   P. p., sulphuric acid.

3. **Ammonium sulphate** (*sulphate of ammonia*).
   N. p., ammonia.
   P. p., sulphuric acid.
4. **Plumbic iodide** (*iodide of lead*).
   N. p., lead.
   P. p., iodine.
5. **Stannous chloride** (*chloride of tin*).
   N. p., tin.
   P. p., chlorine.
6. **Argentic chloride** (*chloride of silver*).
   N. p., silver.
   P. p., chlorine.
7. **Zincic chloride** (*chloride of zinc*).
   N. p., zinc.
   P. p., chlorine.
8. **Hydrochloric acid.**
   N. p., hydrogen.
   P. p., chlorine.
9. **Sulphuric acid.**
   N. p., sulphur.
   P. p., oxygen.
10. **Plumbic acetate** (*acetate of lead*).
    N. p., lead.
    P. p., acetic acid.
11. **Plumbic nitrate** (*nitrate of lead*).
    N. p., lead.
    P. p., nitric acid.
12. **Water.**
    N. p., hydrogen.
    P. p., oxygen.

It is important to have a clear idea of the condition of the battery and the compounds decomposed by its action, and to understand the exact nature and function of each part of the apparatus.

The current is usually generated by the unequal action of a liquid on two solids. Really there are two currents, one generated by the action on each solid. If the two solids be the same, both these currents will be the same in power, and will neutralise each other. But if the chemical action on the metals be unequal, the two currents so generated will be unequal in strength; the weaker will be counterbalanced by a portion of the stronger, and the remaining portion will form the effective strength of the current. Therefore, the greater the difference of the chemical actions, the more practically effective will the resulting current be.

But not only does the galvanic current decompose chemical compounds in the same manner: the *quantities* of the elements released from combination are also invariable. Thus, if zinc be the substance acted upon in the battery, the amount of any other element set free will vary with the amount of zinc dissolved. If I submit hydrochloric acid to the action, I get set free, for every grain of hydrogen, 35.5 grains of chlorine. From chloride of tin I get, with the same force, 118 grains of tin and 71 grains of

chlorine. Notice that this quantity of chlorine is double of the former—

Hydrogen	. . . .	1
Chlorine	. . . .	35.5
Tin	. . . .	118

These are the combining equivalents of these elements. The hydrochloric acid yields one atom of each constituent: the chloride of tin yields one atom of tin and two of chlorine.

(B.) *Deflection of a Magnetic Needle.*—Any small magnet, free to move, is placed more or less at right angles to any wire, through which a current is passing, that is near it. This is described fully under the description of the galvanometer (p. 195).

(C.) *Electric Light.*—I pass a current along a stout wire; no evidence of its passage is given by any development of light or heat. I pass a current of the same strength through other wires, of different thicknesses, and I find that the thinner ones feel warm. I try a very fine wire of platinum, and it is heated to redness by the passage of the current. I try a still finer wire, and it is melted.

Therefore it seems that the thinner the wire, the more difficult for the current to pass, and that the delay in the passage causes heat.

I try first a wire of platinum, so thin as to be raised to redness, and a wire of silver of the same thickness. Whenever I pass the current through, I find that, though the platinum becomes red, the silver gives no such sign of heat. Therefore I infer that silver is a better conductor of electricity than platinum—*i.e.*, a silver wire of any given thickness will conduct more electricity than a platinum wire of the same thickness.

The heat developed by a current when its passage is obstructed may be very great, if the current be powerful. If I separate two points of a circuit, so that the electricity is accumulated at one of them, it will be given off in the form of a spark. The air, being a bad conductor, offers so much resistance as to develop both heat and light. This light is so intense that it will burn under water, because the heat is so great that the water cannot carry it away so fast as it is generated.

The intensity, regularity, and completeness of this light at once suggested the employment of it as a means of illumination. But it requires machinery of a very accurate kind, since it is essential that the two points be kept at precisely the same distance from each other; and this is the more difficult, because small particles of one point pass over to the other continually during the separation which gives the light.

Such a contrivance is called an **electric lamp.** But the lamp is only the machinery for regulating the distance between the points of the wire, the light is developed by the current passing along the wire from the battery, which is outside the lamp. In fact, the lamp is no more than a small enclosure for the two

points between which the spark passes, fitted with machinery for keeping these points in the requisite position by moving them as required. A lamp with less complicated and less expensive machinery is much wanted, and I think might be contrived by using the current more directly.

Since writing this I have seen in action at Mr Browning's two simple and very efficient electric lamps: I have described these below. One of these I have had in use for some time with good results.

This spark will pass between any two conducting substances. In the case of two metal points, the heat seems to melt and vaporise the end of one of them, and the vapour is carried across the interval, forming the conductor of the spark. If I take two points of carbon, I get a more brilliant light than from any other, and this I can do by connecting the two wires from the battery with two short pieces of carbon, which may be pointed for the more ready passage of the spark.

The light so obtained is so brilliant that it will give a shadow to ordinary light—*i.e.*, if I hold a lighted candle before an electric light, not only will the candle be shadowed on the screen, but also the flame. The light is obstructed by the substance of the candle, and also by the substance of the flame, while the light of the candle itself is so small in comparison that it is altogether inappreciable. The electric light is altogether independent of combustion, and does not require the presence of oxygen. It will therefore exist as readily in a vacuum, or under water, as in ordinary air. It is a physical, not a chemical, light.

In fig. 111 is shown the simplest apparatus for the electric light.

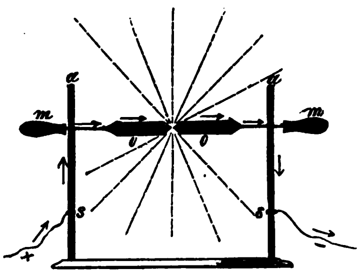


Fig. 111.

Two carbon points, *o o*, are supported by two iron rods *a a*, and can be moved to and from each other by the wooden handles *m m*. Two wires from the battery are fastened to these iron rods at *s s*. The current enters by the + wire, passes up the iron, across the two carbons, down the second rod, and away by the − wire. When the battery is at work, the two points of the carbons must be first made to touch and then be separated slightly, when a light will be apparent, varying in brilliancy with the power of the battery. Two cells, or even one, will give a small spark. But this apparatus is only useful to *show* the spark, not to use it, and requires two hands to keep the carbons at exactly the right distance apart. In fig. 112 is shown an automaton

lamp, invented by Mr Browning, in which the machinery is both simple and effective. The current enters by the left-hand wire (at the bottom of the figure), passes up the metal pillar, round and round a small electro-magnet, fastened like a knapsack to the central pillar, across the top horizontal bar, down the right-hand bar, through the two carbons, and away by the right-hand wire. The only thing required is to keep the upper carbon from resting on the lower, and this is done by means of the small electro-magnet. The tube holding the upper carbon slides freely up and down through a hole at the end of the cross-piece, and if left to its own weight would rest on the lower carbon. But the small magnet has a keeper, to which is fastened a wire that crosses to the carbon tube, and, as it were, grasps it. When the keeper is drawn down to the magnet, this wire tightens and prevents the descent of the carbon. When the keeper is not so drawn down the wire is loosened, and the carbon tube descends.

Fig. 112.

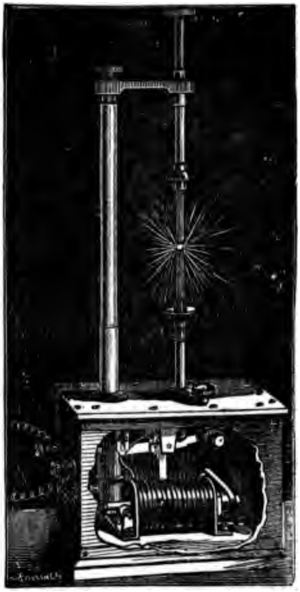


Fig. 113.

The two carbons are together, the upper resting on the lower by its own weight. I connect the wires of the battery, and the current passes through the carbons, as one, and no light exists.

I raise the upper carbon a little, and immediately a brilliant light is given off in all directions. I have set the lamp at work, the magnet keeps it so. In a very short time some of the carbon is vaporised, and the interval between the points is too great for the current to cross. Instantly it ceases to exist, the magnet loses its power, the keeper loosens its hold on the carbon tube, and this descends by its own weight. As soon as it comes sufficiently near, and before the two carbons are in contact, the current is re-established. The magnet draws the keeper, the keeper checks the descent of the carbon. Again the interval becomes too great, and the whole cycle of operation is repeated. In this way the little magnet keeps the carbon points at exactly the right distance apart, and the light shines as a continuous and brilliant spark, though really it goes out and is relit several times in a second. I have had a very effective light for three hours at a time with one of these lamps, the current being supplied by twenty zinc and carbon cells, pint size, charged with dilute sulphuric acid and strong nitric acid.

A larger lamp, also an invention of Mr Browning, and requiring forty or fifty cells, is shown in fig. 113. Here the apparatus is below the lamp, and consists chiefly of an electro-magnet and a lever of unequal arms attached to two parallel iron rods. These are drawn within two coils of wire whenever the current passes, and so move the lever. As before, the work to be done is to keep the carbons as far apart as the current can pass, but no farther. If this limit be exceeded the current ceases, and the lamp goes out. This lamp gives a very brilliant light.

(5.) **Force of Galvanic Currents.**—All galvanic batteries, whatever be their size or power, are in principle the same as the combination of zinc, copper, and acidified water I have described. And such a combination will always produce a current, that can be conducted, measured, and made to do work, just as any other natural force. The force of an electric current is divided in its action, one portion of it goes to overcome the resistance of the liquid to decomposition, the other to overcome the resistance of the wire to the passage of the current.

The resistance of the liquid to the passage of the current (*i.e.* to its own decomposition) increases with the distance of the plates from each other—*i.e.*, with the amount of liquid traversed. The resistance of the wire to the passage of the current through it increases with the length of the wire. But it also decreases if the thickness of the wire be increased.

The force that overcomes these resistances is the chemical affinity between the positive plates of the battery and one of the constituents of the decomposable liquid in which the plates are placed.

The *effective* force of a current—that which is available for any purpose external to the battery and conducting wires (such as telegraphy, analysis, &c.)—is the chemical affinity of the elements,

minus the resistance inside the battery and in the wires; that is, whatever remains of the original force, after these resistances are overcome, is efficient as motive power. Or, to state it still a third way, the chemical affinity of the positive plate for one of the elements of the liquid may be used as *force*, and made to do work, though some of it is consumed in moving the necessary machinery, just as is the case with any other motive power, such as steam or water.

If we use symbols to express the various forces at work in a galvanic battery, we may arrange them and compare them with the aid of formulæ, and apply to their explanation and calculation mathematical methods. Thus, if E be the electrical force with which the positive plate acts on the liquid, R be the resistance of the liquid to decomposition, and r the resistance of the wire to the passage of the current, then—

$E - (R + r) =$ the available effective force of the current.

It is important to distinguish between R and r. If the battery be used for chemical analysis, r is very small (because the wires are very short), and may be reduced to a minimum by the use of good conductors. Then we may, practically, disregard it, and—

$E - R =$ the available effective force of the current.

If, however, the battery be used for telegraphy, and the wires be very long, then r becomes of paramount importance, and R, by comparison, unimportant. Then, practically, we have—

$E - r =$ available force of current.

We must regard electricity as a force, and the battery and wire as the machinery. We must separate the one from the other, considering the battery and its arrangements only necessary for the collection and direction of the force, which is essentially derived from the chemical action between the positive plate and the liquid.

We must also get a clear conception of the relations of the different portions of the battery to each other, and of the functions they have to perform. And it is equally important to understand how these relations and functions may be affected by changes in the nature, size, form, and relative position, of these constituents of the battery. Thus E is increased by the increase of the action between the positive plate and the liquid, which may be caused by changing the plates, or the liquid—as, for instance, when zinc is substituted for copper.

R is increased by removing the positive and negative plates farther apart, and is decreased by bringing them more closely together. R is also increased by diminishing the size of the plates, and decreased by enlarging them.

The resistance of the wire r may be increased by using finer wire, or decreased by using thicker. It also becomes greater as the length of wire is increased, and less if the wire be shortened.

So that R varies with D, the distance of the plates—*i.e.*, the distance the current has to traverse; just as r varies with l the length of the wire—*i.e.*, again, the distance the current has to traverse.

Also R varies *inversely* with S, the surface of the plates—*i.e.*, the thickness of the stratum of water the current has to traverse; just as r varies inversely with w, the thickness of the wire—*i.e.*, the stratum of metal the current has to traverse.

Therefore R, like r, is greater for a long distance than for a short one, and is less for a thick conductor (whether liquid or solid) than for a thin one.

So that if by R we express the work done within the battery itself, by r the work done in passing along the wires, and by W the work done by the galvanic force, such as deflection of a magnet, chemical analysis, electric light, &c., then—

$$E = R + r + W$$

i.e., the chemical affinity of the two elements in the battery is capable of overcoming all the three resistances R, r, and W.

But the equation $E-(R + r) = W$, which is the same as $E = R + r + W$, is here given *as true of one cell only.* The question of the amount of effective force in a *battery*, and how it is modified by the addition, subtraction, or rearrangement of cells in a battery, has been discussed by Ohm, and it is important to understand the reasoning he gives, as well as the formula he adopts.

In the equation $E = R + r + W$, it will be necessary to alter W to I in order to assimilate the equation to Ohm's. We have spoken of W as the *work* which a battery can do; Ohm speaks of the *intensity* of the current; really the two are the same, so far as measurement is concerned. I used W because the work done was a tangible way of measurement. Substituting I for W—*i.e.*, speaking of the *power of work* instead of the work itself—we have

$$E = R + r + I \text{; and this may be changed to}$$

$$I = E-(R + r)$$

We have now to consider what can increase or decrease E, R, or r. E, or electric force, can be increased by using a more oxidisable positive or a less oxidisable negative; and decreased by reversing this.

R, or *internal* resistance, can be increased by putting the plates farther apart, or by decreasing their size; and decreased by putting them closer together, or increasing their size.

r, or *external* resistance, can be increased by using longer wires, or finer wires; and decreased by the use of shorter or thicker wires.

I have two batteries. The power of one I know, the power of the other I desire to know without the serious trouble of experimenting with it. It is important to be able to estimate this power approximately by calculation, because it is a work of some hours to get a large battery fairly to work and put away again.

Or I may desire to know what would be the power of a battery, which I already know under certain conditions, when those conditions are changed, as they may be by change of length or thickness of wire, of liquid, of size of plates, &c.

Let I be the known intensity, then I′ will represent the new intensity required.

Also E, R, and r will represent the old arrangement, which gives I. Then E′, R′, and r' represent the new arrangement, the result of which is represented by I′, the value of which is not known.

It is now an ordinary rule-of-three sum, or (to use more correctly mathematical language) a question of proportion.

$$I : I' :: E : E'$$

i.e., the intensity (I) varies *directly* with the electric force (E).

$$\text{Also, } I : I' :: R' : R$$

i.e., the intensity (I) varies *inversely* with the internal resistance (R).

$$\text{Lastly, } I : I' :: r' : r$$

i.e., the intensity (I) varies *inversely* with the external resistance (r). Putting these together we get

$$I : I' :: \left\{ \begin{array}{l} E : E' \\ R' : R \\ r' : r \end{array} \right.$$

and expressing this as an equation, we have

$$I\,(E' \times R \times r) = I'\,(E \times R' \times r')$$

$$\therefore I' = I\,\frac{E' \times R \times r}{E \times R' \times r'}$$

Now, we may take I, E, R, and r as each equal to unity, as being the standards of comparison. Then

$$I' = 1\,\frac{E' \times 1 \times 1}{1 \times R' \times r'}$$

and omitting the unity factors, we have

$$I = \frac{E'}{R' \times r'}$$

which is the formula given by Ohm.

This is usually explained by saying that the intensity varies directly with the electric force, and inversely with the resistances. Knowing how much difficulty this formula has been to students, I have explained more fully how it is obtained.

One important result of this formula is the knowledge how to arrange any given number of cells so as to obtain a battery of the greatest power possible under the given circumstances. I have discussed this subject separately.

(6.) **Measurement of Galvanic Force.**—If I desire to mea-

sure the strength of a galvanic current, the most convenient method is either to notice its effect upon a magnetic needle, or the amount of chemical decomposition it can effect in a given time. It may be objected that these are means of comparison only, not absolute measurements; but a moment's thought will show that this is exactly the case with all other measurements. I measure time by comparing the duration of some process with some fraction of the duration of the earth's passage round the sun, or with the duration of one revolution of the earth on its own axis. I measure the weight of any body by measuring the force with which the earth pulls it as compared with its attraction for other objects. I measure the size of anything by comparing its magnitude with some other magnitude. I measure galvanic force by comparison with some known result effected by that force, just as I measure time by some known time, or gravitation by some known effect of gravity. But time and gravitation are familiarly known to all people—and the accepted units of measurement, such as a year, a day, a pound, a kilogramme, are equally well known; while galvanism, being not yet of general use, and where used, used practically without much reference to theoretical measurement, is almost unknown except in a general and vague manner. But it is only this want of familiarity with it that prevents the measurement of galvanic force from being at least as well understood as the measurement of time or weight.

I have, then, to fix upon some definite amount of deflection of a magnetic needle, or of chemical decomposition, by means of a galvanic current, and I am in a position to measure accurately the force of any battery by comparing its power in producing deflection or decomposition with the unit determined upon.

To take first the effect of a current on a magnetic needle. It must be borne in mind that such a needle has a determinate position nearly north and south by virtue of its magnetic quality. I must be careful, therefore, not to attribute any result of its magnetic property to galvanic force, nor *vice versâ*. How shall I arrange my galvanic wire and magnetic needle so as to be able to distinguish clearly between the two forces? Obviously the best way will be to counteract one force, so that the other only will have any sensible results. Obviously, also, it will not do to counteract the galvanic force, since that is the one I desire to measure. Have I any means, then, of so compensating the magnetic force as to prevent it disturbing the result obtained by the action of the galvanic current? which action will only take effect upon a needle that is magnetic, so that I must compensate, not destroy, its magnetism.

An ordinary magnetic needle, when suspended freely on its centre of gravity, points nearly N. and S. If I put two side by side, each will, independently, lie in this direction. But if I fasten them together so that they are reversed—*i.e.*, the N. of one to the S. end of the other—the two will act in contrary directions,

and the result will be that each needle will counteract the other, and the compound needle will remain at rest in any position. Such a needle is called an **astatic needle**, and possesses all the magnetic virtue necessary to its deflection by a galvanic current, without the (for this purpose) inconvenient polar force of the ordinary magnetic state.

Such a combination of two needles, having their poles reversed, and fastened together, at a little distance, so that both move together, is shown in fig. 114. Neither is moved magnetically, because their tensions counteract each other. But a wire through which a current is passing has the power of deflecting the compound needle.

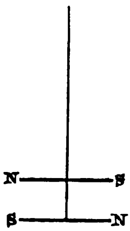


Fig. 114.

If, then, I place a small double needle of this kind near the conducting wire of a galvanic battery, I get invariably the same amount of deflection, and in the same direction, for any given strength of current. In fact, the amount of deflection measures the strength of the current.

I let the wire stretch above a needle, and send a current through it. The needle immediately turns with an amount of deflection according to the strength of current, so that its N. pole points towards the left-hand side of the wire—*i.e.*, to the left hand of a person facing in the direction of the current. Thus, if the needle point N. and S.—*i.e.*, magnetically at rest—and the current pass from S. to N., then the N. pole turns towards the W. But if, the needle still being N. and S., the current pass from N. to S., then the N. pole turns towards the E.

So that with the same needle and same wire the deflection of the needle may be reversed by simply reversing the direction of the current.

Let the current go from left to right, as in fig. 115, and let the needle, an ordinary magnet, as in fig. 116, be below. The presence of the current in the wire will at once be shown by the motion of the needle, which will turn *across* the wire, with its N pole to the left of the wire.

Fig. 115.

Fig. 116.

I have supposed here an ordinary needle—not an astatic one—lying in its magnetically natural position nearly N. and S., and an ordinary wire passing over it.

If now I arrange the wire so that it shall pass below instead of above the needle, will there be any difference of result? I try the experiment, and find the effect to be precisely the opposite of the previous result. Thus, if the current pass from S. to N., the needle points with its N. pole towards the E., while if it pass from N. to S., the N. pole turns to the W.

I now double the wire, so that it passes above the needle from

S. to N., and then returns below the needle from N. to S. Sending a current along the wire thus doubled, I get a greater deflection of the needle, the direction of which varies with that of the current. If it pass from S. to N. above the needle, the result is, as before, a deflection of N. pole of the needle towards W.; the current, then returning from N. to S. below the needle, produces, as before, a deflection in the same direction. The result is the same as if I had placed one wire above the needle and another below it, and sent a current through each—one from S. to N., and the other from N. to S. The effect of either separately would be a deflection to the W., the combined result of both is a stronger deflection in that direction.

If now I reverse the current, so that it pass first below from S. to N., and then above from N. to S., I get an equally strong turning of the needle to the E.

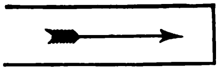


Fig. 117.

By bending the wire to and fro, first above and then below the needle, I can multiply the effect upon the needle by as many times as I pass the wire to and fro. In this way I can make the turning of the needle a measure of even very weak currents. If the wire pass to and fro twice, I get the result of a current four times as strong, because it passes along the needle four times; if it pass to and fro twenty times, I multiply the result forty times,—and so on.

But this is using only an ordinary magnetic needle, which requires to be kept in exactly its magnetic meridian. To avoid this restriction I replace it by an astatic (or double) needle, as described above.

The wire is bent to and fro several times, and the double needle placed so that one needle is within the coil and the other without it. The lower needle is acted upon by the wires above and the wires below, both tending to turn it in one direction; the upper needle chiefly by the upper wires, and but little by the lower ones,—the first of these tends to turn the upper needle in accordance with the lower one.

Both wires act on both needles, so that there are four actions, three of which tend to turn the compound needle in one direction, while the fourth (the weakest) tends to turn the upper needle in the other direction. The upper wires being above the lower needle and below the upper, a current passing along them would tend to turn the two needles in different directions, but the needles being reversed reverses this, so that the needle is acted on powerfully, and shows the presence of even very weak galvanic force.

In fig. 118 I have shown an astatic needle, the wire folding to and fro, and the direction of the current. The two magnets, *a* and *b*, are suspended by the thread *s*, and the wire *o* is much nearer the needle *b*, so that its action is much more powerful on *b* than on *a*, because of the difference in the distances. I

have shown only four folds of the wire, but these are enough to illustrate the action. The current enters by the lower wire and passes *below* both needles. This tends to turn *b* one way (which we will call B), and *a* the other (which we will call A). These partially counteract each other, but B is the stronger by reason of the nearness of *b*. The current then returns *between* the wires. This tends to turn *a* and *b* both in the same direction, B. So that the first two folds tend to turn both needles in the same direction: the next two turns of the wire just double the effect; and any other folds increase it still more.

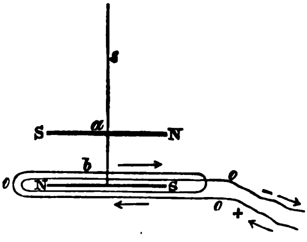


Fig. 118.

The coils of wire have to be very carefully kept distinct from each other, so that the current cannot pass from one to the other except by going through the whole length of the wire. This is attained by carefully covering each wire with fine silk, gutta percha, or some other good insulating substance. If this were not done, the several wires lying beside each other would become, electrically, one conductor of greater thickness, and therefore better conducting power, but would not carry the current round and round the needle, but only once, and in this way the needle would cease to be a multiplier—*i.e.*, the needle would be deflected with the force derived from one current only.

The ordinary needle, lying in the magnetic meridian, when acted on by a current, moves under the influence of two forces,—one the magnetic, that tends to keep it N. and S.—the other the galvanic, that tends to place it E. and W. Its final position is the resultant between these forces. If they be equal, it settles at 45°—*i.e.*, halfway between the two positions. If the current be stronger than the magnetic force, the needle is deflected more than halfway; if less, less.

In the case of the astatic needle, however, this magnetic force is got rid of; but still, when the current is strong enough to deflect the needle more than 45°, the measurement is not so accurate as in the case of weaker currents. When the needle is already deflected by a given current, any increased strength of the current does not act at right angles to the needle, and therefore does not exert its full force upon it. A given force moves the needle 10°; twice that force will not deflect it 20°, and four times the force will be still farther from moving it 40°, because the greater the deflection of the needle the greater the loss of power. This is a well-known law in mechanics.

If, therefore, I wish to measure, by this method, a strong current, the most accurate contrivance is to counteract a great portion of the current by another of known strength, so that the needle is

deflected only by the excess of the greater current over the less. This produces but a small deflection of the needle, which is, as we have seen, an accurate measure for such small deflections. The strength known to be required for this deflection, added to the strength of the lesser current, gives the strength of the greater current. In this way an astatic needle will measure strong currents, and by itself it will measure weak ones.

Practically, however, the astatic galvanometer is not used for measurement of small currents. For currents of very small power, another galvanometer is found preferable.

(7.) **Tangent Galvanometer.**—An ordinary magnetic needle is suspended freely in the centre of a copper hoop, about one foot or more in diameter. The hoop is placed so that its position coincides with that of the needle, which is determined by the magnetic meridian. The needle then points directly across the hoop, passing through its centre, and forming a part of a diameter. The copper hoop, which from its nature is a good conductor, and by its thickness almost a perfect one, is placed in connection with the poles of a battery, so that the current passes round it. This is really the same arrangement as the simple doubling of a conducting wire round a needle just described (p. 196), only that the wire is farther from the needle, and bent in a circle. Also the copper circle being thick offers but exceedingly small resistance to the current, which enables a more accurate measurement to be expressed by the needle than when part of the current is used in overcoming the resistance of a fine wire.

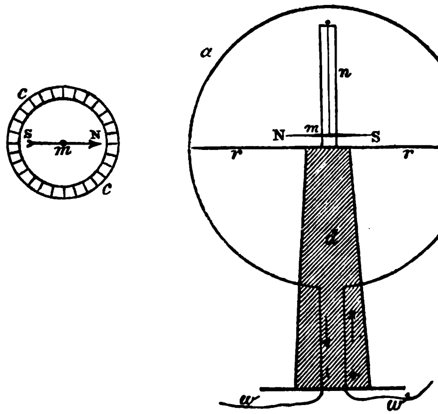
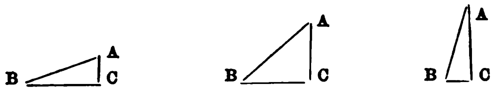


Fig. 119.

In fig. 119 *m* is the needle, suspended by a thread *n*, and surrounded by the copper hoop *a*, which terminates in the wires *w*

by which (by means of screws or mercury cups) the apparatus is connected with the battery or wires whose tension is to be measured. A stand, *d*, is a support of the whole. Sometimes, instead of the wire *n* supporting the needle *m*, it is placed in a small frame *c*, on the cross-piece *r r*, resting on the stand *d*. In either case there is a graduated circle, as at *c*, to show how far the needle is deflected from its normal position.

The needle is acted upon by two forces,—one the magnetic, tending to keep it motionless—the other the galvanic, tending to place it at right angles to the plane of the hoop. Between these two, the needle takes up an intermediate position, nearer to that which would be the result of the greater force. If the forces be equal, the position is exactly halfway—*i. e.*, at 45° to the plane of the hoop.



If A B be the position taken by the needle, and B C the original position, then A C will represent the diverting force of the current, and B C the restraining force of the magnetism of the earth. The angle A B C will increase with A C—*i.e.*, with the strength of the current; and to those who understand the elements of trigonometry, the expression "tangent of B varies with the current strength" conveys very accurately and briefly the theory of the tangent galvanometer.

The angle B becomes greater with a greater current, but does not vary at the same rate. But the two lines A C, B C always represent *accurately* the comparative strengths of the two currents. That is, to put it as a question of proportion :—

$$\text{A C} : \text{B C} :: \text{current strength} : \text{magnetic strength}.$$

$$\therefore \frac{\text{A C}}{\text{B C}} = \frac{\text{current strength.}}{\text{magnetic strength.}}$$

But $\frac{\text{A C}}{\text{B C}}$ is the tangent of the angle B, so that since the magnetic force remains unaltered (*i.e.*, B C remains constant), the fraction $\frac{\text{A C}}{\text{B C}}$ increases as the current strength increases. Thus, *not* the angle B, but the fraction $\frac{\text{A C}}{\text{B C}}$ (*i.e.*, tangent B) measures the increase of the current force.

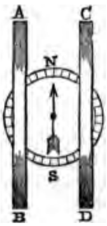


Fig. 120.

There is another *tangent galvanometer* in which the needle, instead of being in the centre of one hoop, is between the centres of two, placed side by side at some little distance.

A B and C D being the two hoops of copper, the needle is placed in the centre, and is deflected by the conjoined efforts of the two hoops, round both of which the current is sent.

(8.) **The Voltameter.**—The second, and for some reasons preferable, method of estimating galvanic strength, is by measuring the amount of chemical decomposition performed in a given time.

This is effected by connecting the wires of a battery with two small plates of platinum, or other non-oxidisable metal, which are inserted in the liquid (usually water) to be decomposed. The plates (or electrodes) are placed slightly apart, and on passing a current through the wires, the circuit is completed by the polarisation of the water intervening between the plates. This water is decomposed, as in the case of the liquid in the battery itself, and is given off as gas, the oxygen at the positive plate, the hydrogen at the negative. Water is always the same, and the same galvanic force will always decompose the same quantity in any given time. So that this method of measurement has an advantage over that by the galvanometer, in that its operation at any time or place can be compared with the work of any other voltameter (as the apparatus for decomposing water and measuring the gases is called) at any other time and place; while one galvanometer cannot be so compared with another, except it happen that the two needles have exactly the same magnetic strength, and keep their strengths unaltered—both of which are very improbable.

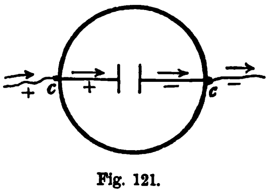


Fig. 121.

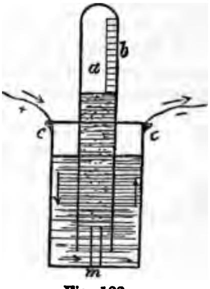


Fig. 122.

In fig. 122 I have shown a voltameter, consisting of a glass vessel, *c c*, nearly full of water, in which a tube, *a*, quite full, is inverted. At *c c* two small screws, or mercury cups, receive the + and − wires of the battery. At *m*, at the foot of the glass, are two platinum plates, very close together. These are connected with the wires at *c c* by flat bands of metal lying close to the glass. The current, entering at *c* by the + wire, descends one side of the glass, crosses from one platinum plate to the other, reaches

c by the opposite metal, and returns to the battery by the − wire. The water between the plates *m* is polarised and decomposed by the passage of the current, and its constituent gases rise in the tube *a*, displacing the water, and the quantity of gas present is shown by the graduated scale *b*. At fig. 121 is a view of the wires and platinum plates, or electrodes, as seen from above.

(9.) **Estimation of Galvanic Force.**—Force cannot be weighed or measured like matter; but it is yet essential that we should be able to compare one force with another, to estimate the unknown by comparison with the known. This is all we do in our familiar measurements of time, space, or quantity, only that the familiarity prevents our recognition of this fact. In the case of galvanic force, we usually measure it by the resistance necessary to overcome it. In the same way we measure the weight of a stone by finding how many known weights will overcome its tendency to fall, or the quantity of a liquid by finding how many times it will fill a known measure.

Speaking generally, any galvanic force is measured by allowing it to disturb some equilibrial arrangement, and then compensating this disturbance by forces of which we know the measurement. This is exactly what we do when we weigh anything for the purpose of ascertaining its weight. We take a pair of scales,—*i.e.*, an "equilibrial arrangement," and by putting the thing to be weighed in one scale, allow it to disturb this equilibrium. We then compensate this disturbance, and restore the balance, by putting in the opposite scale a sufficient number of known weights. The number of these we take as the measure of weight of the disturbing body. It is more important to get this principle of measurement into the mind than to understand the precise arrangement of any of the numerous machineries for measuring force; because the principle being well grasped, there will be no difficulty in seeing the purpose and method of any given instrument; while the instruments themselves are constantly assuming new and different forms, though the principles are unaltered.

(A.) The *Rheostat* is an instrument of this kind, though its utility is less as a measurer of electric force than as a measure of resistance to that force—*i. e.*, of measuring the resistance of any given length of wire, or any other conducting body, and which may afterwards be used as a measure of force. Thus, to measure the resistance of a body is to measure the force necessary to overcome that resistance. I have a mile of copper wire, and I wish to know what force will send a current through its whole length. I do this by ascertaining what resistance the wire interposes to the passage of a current.

I take a cylinder of well-baked wood and wind on it a fine wire, cutting for the wire a groove in the wood, so that no two coils are in contact. By this means it is secured that a current entering at one end of the wire must pass throughout its

whole length, since the wood is a non-conductor. If a pipe were wound round a column, any water poured in at one end could only reach the other by passing through the whole length of the pipe, round and round the column. So a current has to pass round and round the cylinder of wood, along the whole length of the wire. I place beside this wooden non-conducting cylinder a conducting cylinder of brass, and after winding the wire round the whole length of the wooden cylinder I fasten the end of it to the brass cylinder. Both the cylinders are made to revolve by means of a small handle, and as I turn the brass one in one direction I wind the wire on to it and off the wooden cylinder. This I can do to any extent I please. I can wind the wire either all on the wood, all on the brass, or partly on each. I attach one end of each cylinder to a battery, so that the current shall pass round and round the wooden cylinder by means of the wire, then along the wire to the brass cylinder, down which (it being a conductor) it passes back to the battery. In this way the portion of the wire on the brass cylinder is removed from the action of the current, which traverses only that part of it which is wound on the wooden cylinder.

The construction of a rheostat is shown in fig. 123, where *a* is the wooden, and *c* the brass cylinder, *s* the graduated bar between, crossed by the wire. The handle *o* turns both cylinders. The current enters by the + wire, traverses the wire on the wooden cylinder, crosses by the wire to the brass, and then, preferring the broad brass conductor to the fine wire one, returns to the − wire, by which it leaves.

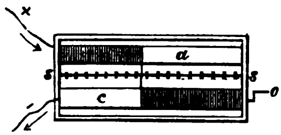


Fig. 123.

The whole wire being on the wooden cylinder, I attach the wires of a battery to the rheostat, placing also a galvanometer in the circuit. The needle is of course deflected by the current; the amount of deflection I notice. I now take any substance whose resisting power I wish to measure, say a coil of wire. This I insert in the circuit so that the current has to traverse its whole length. This I do by breaking the circuit, and attaching the ends so made, one to each end of the coil, taking care to keep the coils from contact. The coil thus introduced necessarily weakens the force of the current on the galvanometer, and the needle returns towards zero. I now unwind part of the rheostat coil off the wooden cylinder, by winding it on to the brass one, and in this way remove part of it from the action of the current. As I thus reduce the resistance, the galvanometer needle gradually returns to its original position. When it stands where it stood before I inserted the coil, whose resistance I desire to measure, I note the length of the wire I have wound on to the brass cylinder. The resistance of this length is exactly equal to the resistance of the

introduced coil. If all rheostats were alike in size, arrangement, and detail, the number of turns of the cylinder would be a recognised and easily-understood measure. But in practice they are not so, and many attempts have been made to devise some satisfactory unit of electrical force.

But by means of any rheostat we have a ready and accurate means of comparing the resistances of any number of substances. Thus, if I insert successively three coils of wire in the circuit, and find that the number of turns of the rheostat is, respectively, 9, 18, and 27, then I say that the force required to overcome the resistance of these coils is, in the first case, 1; in the second, 2; and in the third, 3. What the 1 expresses I know not; but whatever it be, the second coil offers twice, and the third thrice, the resistance expressed by it. In this way the rheostat enables us to compare the resistances offered by any number of conducting bodies.

(B.) *Wheatstone's Bridge.*—Another contrivance is somewhat similar, and is called Wheatstone's bridge. A wire is arranged on a board in the shape of a diamond, ACBD. A current enters at A and passes out at B, when these points are connected with the positive and negative poles of a battery. From C and D wires lead to a galvanometer,

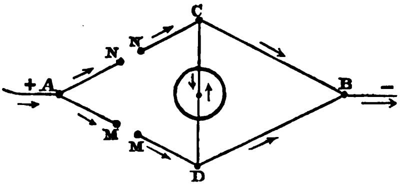


Fig. 124.

which may be placed anywhere else as well as between C and D. The current entering at A passes half along A C and half along A D. At C and D these weakened currents are again divided, parts passing along C B and D B to the negative pole, and parts through C D B and D C B to B, and thence to the negative pole. Only these latter parts have effect on the galvanometer; and these being equal and opposite, neutralise each other, and the needle remains at zero. Thus one single current, by being subdivided, passes through the galvanometer without deflecting the needle.

I now use the bridge in much the same way as the rheostat; I break the circuit at some point, say M, between the point where the current enters and the galvanometer—*i.e.*, some point in A C or A D. In the opening thus made I insert the coil of wire whose resistance I desire to measure. The current passing through A M D to the galvanometer meets with more resistance (because of the interposed wire) than the portion passing through A C, and the needle is consequently deflected by the preponderance of the force that meets with the least resistance. By interposing in this second, and hitherto unbroken, part of the current, some wire whose resisting power I know, increasing the quantity until I

bring the needle again to zero, I am able to estimate the resistance of the wire to be measured. Or I can place a rheostat at N.

Thus, as before, I can compare the resistances of any number of substances, and can compare each with the substance I use as a standard. But here again, as in the rheostat, I have no generally accepted standard of resistance. It would seem very easy to set up such a standard, but the difficulties are numerous, and of a character not easily removable.

(10.) **Unit of Resistance.**—It would seem easy enough to take a length of copper wire, say a mile, of uniform thickness, and having tested its resisting power, fix that as a standard of resistance. But it is found that no two equal lengths of wire give the same amount of resistance, probably from the differences of atomic arrangement. Twisting a wire will increase its resisting power, by altering the arrangement of its molecules, some being more crowded and others less so than before. This being understood, it will be easy to perceive the difficulty of finding two long lengths of wire that shall be alike in all the points affecting the resisting power to an electric current. For instance, it would manifestly be impossible to find a mile of copper wire, of any thickness, having no twist in it. Secondly, there is the difficulty of ascertaining that the wire is copper, and nothing but copper. No two substances have exactly the same resisting power, so that any admixture of another substance with the copper would affect it, and to get any substance chemically pure—*i. e.*, absolutely free from any admixture—is exceedingly difficult.

But supposing all these difficulties to be overcome—as they may be, for instance, by taking the average of a great number of experiments, or by other methods—and that we have an approximately correct measure of the resistance of a mile of copper wire of given thickness. Whenever we express by this standard the resisting power of any particular length of copper wire, that has not been actually tried, we have no means of deciding that it may not be as much above or below the average as the highest or lowest of our results from which we obtained the average.

Other measurements than those of wire have been tried, in order to get rid of the special difficulties presented by their use. Thin wires are so much more liable to suffer by slight injury than thick ones, and thick ones require to be longer because of their greater conducting power, and therefore less resisting power. Also, the repeated passage of currents through tends to heat them, especially if thin, and so to alter their structure.

One method tried has been the use of a column of mercury. This removes the difficulties peculiar to a solid wire, but has others peculiar to a liquid, besides being, like the wire, liable to admixture.

To avoid all these difficulties, arising from the imperfections or nature of the materials used, it has been suggested to use an ab-

solute measurement as a unit of resistance, and to refer all others to it. This was done by taking a definite velocity as the standard, and measuring all actual velocities by it as a unit. Thus the velocity of 10,000,000 metres per second is assumed to be such a unit, and therefore called 1.

(11.) **Secondary Current.**—We saw (p. 156) that an electrified rod of glass held near an electroscope affected it without any loss of its own power, or any transfer of matter; also (p. 197) we saw that an electric wire and a magnet affected each other. Is there any such influence between two wires, one being electrified and the other not? Or, to word the question in another way, can galvanic force induce galvanic force? By *induction* is not meant *transfer;* to induce a current is not to impart a portion of an already existing current to a neutral wire, but to call forth another such current in the wire itself. Just as, to use a moral parallel, an angry man induces anger in others without losing any of his own, and very frequently with even a reverse inductive effect, each current of anger increasing the other without being itself diminished. This parallel between electricity and morals might be pushed further than at first sight appears reasonable. It would not be impossible to set up a theory of electrical force being the moral force of physics.

If a magnet were not a magnet, its motion when near a galvanised wire would be an answer to the question; but its motion is due to its magnetisation, not to a purely galvanic force called forth by another force of the same kind.

To find whether such induction does ordinarily occur in galvanism, I place two wires side by side, but not in contact,—one being in connection with a battery, so that I know when a current passes through it—and the other in connection with a galvanometer, which will tell me if any galvanic effect be produced on the second wire when the first is excited.

Accordingly, I send a current through one of the wires, and I find that during the existence of the current the galvanometer shows no signs of any such current. But at the instant I send the current through, and also at the instant I destroy it by breaking the circuit, I perceive a movement of the needle of the galvanometer. However frequently I make and break the circuit, and so send or interrupt the current, just so frequently I deflect the needle first to the right hand and then to the left.

So that it would appear that though the presence of a current in one wire has not force to induce a secondary current in another, yet there is sufficient force in the change that takes place when a wire is first electrified, and when it is allowed to return to its normal state, to affect another wire.

To exhibit this phenomenon to advantage, and to utilise the force thus found to exist, it is necessary to have some means of making and breaking the current very frequently. This is done

by many expedients, the most effective of which is to combine the forces of electricity and magnetism, so as to induce one by the other.

Thus it is found that the insertion of a magnet within a coil of wire is sufficient to send a current of electricity through it. It is also found that one wire acts most efficiently upon a second, when they are each arranged in a coil, and one coil placed within the other. Thus I place a magnet within one coil of wire: this sends a current through it; and this primary current induces a secondary current in a second coil, if one be placed round the first coil.

Precisely the same effect would occur if, instead of inserting a magnet in the primary coil, I used an ordinary galvanic battery for the purpose of passing a current through it. That is, I have two coils of wire, A and B, one within the other. I send a current through the inner coil A, either from a galvanic battery, or by inserting a magnet within it. In either case the primary current in coil A induces a secondary current in coil B.

One advantage of using a magnet is the greater quickness in obtaining the desired result, and the greater simplicity in the use of a magnet over the preparation and arrangement of a galvanic battery. But the magnet must be inserted and withdrawn rapidly and regularly, and for this some mechanical contrivance is necessary.

Since the secondary current is but momentary in its existence, and can only be excited by either making or breaking the galvanic circuit, or inserting or withdrawing the magnet, it is necessary to provide some means for alternately making and breaking the circuit, or inserting and withdrawing the magnet with both regularity and rapidity. In the case of the magnet, this same effect may be best produced, not by moving the magnet to and fro, but by using a bar of soft iron, which is alternately magnetised and demagnetised by means of electricity. So that we first use chemical affinity to produce a galvanic current, then this current to induce magnetism, then this magnetism to break the galvanic current, and then the primary current to induce a secondary current. It might also be objected that we first use a magnet to save using a battery, and then use a battery to excite the magnet. But it is essential that force should be excited: it cannot be created. And to excite this force we must either use a permanent magnet or a galvanic battery, whichever may be more convenient for the special case we have in hand.

In one of the most common forms of the *induction-coil*, the primary helix of wire is electrified by means of a galvanic battery of about four elements. This primary current both excites a secondary current in an outer helix, and also magnetises a bar of soft iron inserted within the primary coil. The magnet (*i.e.*, the magnetised soft iron) at once draws aside by its attraction a movable portion of the primary coil, so as to break the circuit. Instantly the current ceases, and in ceasing again excites a secondary current, while the soft iron bar loses its magnetic power. The

portion of the wire it had drawn aside immediately returns to its place, and the primary current is at once re-established, again inducing a secondary current in the outer coil, and again magnetising the bar of soft iron. This again breaks the circuit, and again a secondary current is excited.

The current is here excited by the battery, and is continually being broken by the suicidal power of the magnet. Each time the current is made or broken, a secondary current is induced in the outer coil; and the whole object of the primary current, the magnetisation of the soft iron bar, and the continual interruption of the current by its agency, is to establish a rapid succession of these secondary currents, which are excited whenever the primary current commences or ceases, but do not exist during its continuance.

An ordinary induction-coil is shown in fig. 126. The stand *a a* supports an electro-magnet M, surrounded by the primary coil P P, and the secondary coil S S. These are seen in section in fig. 126, and endwise from above in fig. 125. The magnet passes through the stand *a*, beneath which is a lever *c* moving on the axis *d*, with its heavy end resting on the small anvil *b*. The current of the primary coil enters at the bottom by the + wire, passes through *d c* and *b* into the coil P. After traversing the whole length of this it returns to the battery by the – wire shown in the figure at the top. The secondary coil S S has also a + wire and a – wire, which are almost in contact. When the machine is inactive, the hammer *c* is resting on the anvil *b*. A current from a battery is sent through *d c b* and P. The soft iron bar M instantly becomes a magnet, and by its action draws the iron lever *c* away from *b*. This breaks the current; the bar M ceases to be a magnet; the lever *c* falls by its weight upon *b*. The current has been made and broken once. The whole apparatus is as it was. But the whole is instantly repeated, because the contact of *c* with *b* again completes the circuit, and M is again magnetised, again lifts *c*, and so again breaks the circuit, &c. This continues so long as the connection with the battery

Fig. 125.

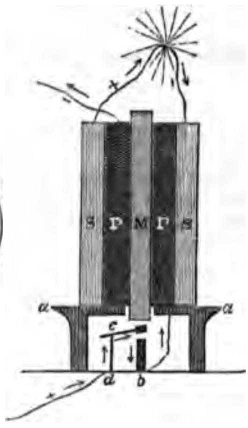


Fig. 126.

exists. The apparatus is here shown as vertical, but it is as often arranged horizontally. Also the magnet need not be in the coil itself. An ordinary commutator, worked by an electro-magnet, might easily be arranged at any point in the circuit.

Tertiary Currents, &c.—A secondary current is as truly a current as a primary one while it exists, and therefore has the power of itself inducing other currents. The current excited by a secondary current is naturally called a tertiary current. This tertiary current will also have the power *of inducing* a fourth or quaternary current. These successive currents naturally decrease in power, and each is always the reverse of the one preceding it. Thus we have (if there be a series of successive and insulated coils)—

The primary current, . . .	direct.
The secondary ,, . . .	inverse.
The tertiary ,, . . .	direct.
The quaternary ,, . . .	inverse.

When I break the primary current I get—

The secondary current, . .	direct.
The tertiary ,, . . .	inverse.
The quaternary ,, . . .	direct.

Galvanic Apparatus.—So much of this has necessarily been described in the text that it is needless to repeat the description here. Reference to each piece of apparatus will be found in the index at the end.

SUMMARY.

SOME metals, such as potassium and zinc, have so great an affinity for oxygen that they will decompose water when in contact with it, and combine with the oxygen so set free. Just as friction produces electricity, so does this decomposition of water by oxidisable substance. The electricity so produced is called **galvanic or voltaic electricity.** Page 177.

Therefore galvanism is said to be a **chemical effect.** Page 180.

To utilise the galvanic force it is necessary to have an arrangement called a **galvanic battery,** consisting essentially of two substances, one more oxidisable than the other, and a liquid to be decomposed by the oxidisable substance. Page 181.

The **effects** of galvanism are, chemical decomposition; deflection of magnetic needles; development of heat and light. Page 184.

In estimating the strength of a galvanic current, three things have to be considered: the intensity of the chemical action within the battery, usually expressed by E; the amount of force expended in decomposing the liquid in the battery, called R; and the work to be done in sending the force through the wires outside the battery, called r. Page 190.

The strength of a battery is expressed by **Ohm** thus, $I = \frac{E}{R+r}$ meaning that the intensity of the force in the wires varies *directly* with the chemical action, but *inversely* with the work in the battery and in the wires. This is called **Ohm's Law.** Page 193.

Galvanic force may be measured by the amount of deflection of a magnetic needle. Page 194.

The needle most used for this purpose is a double one, called an **astatic needle.** Page 195.

Another variety of the same method of measurement is by the **tangent galvanometer.** Page 198.

But the galvanic force may also be measured by the amount of chemical decomposition that can be effected by it. The apparatus used for this is called a **voltameter.** Page 200.

It is also necessary to measure the resistance of any given body to the passage of electricity through it. The apparatus used for this is called the **rheostat.** Page 201.

Another apparatus for the same purpose is called **Wheatstone's bridge.** Page 203.

A current passing through one wire excites a similar current in another wire near it, at the moment the current begins or ceases, but not during its continuance. A current so excited is called a **secondary current.** Page 205.

The apparatus for utilising these secondary currents is called an **induction-coil.** Page 207.

TELEGRAPHY,

CONSIDERED AS A PRACTICAL APPLICATION OF GALVANISM.

(12.) **General Principles.**—We have seen (p. 195) that a magnetic needle of small size is deflected by a galvanic current passing through a wire near it; also, that a current may be interrupted and restored many times even in a second. These results are quite independent of the length of the wire, or the distance of the needle from the battery which is the source of the power, excepting that the power of the current decreases with the length of the wire.

Since, then, we can move a needle at any distance from the battery, provided that a wire pass from the battery through the whole intervening distance, there are only the practical difficulties in the way of establishing any preconcerted scheme of signals by which a person near the battery may communicate with, and receive communications from, a person near the needle; or, to speak more generally, by which any two persons at any two points in a galvanic circuit may exchange signals, provided that each has the means of breaking and remaking the current at will, so that he can transmit signals; and has near him a needle, so that he can receive them. The longest telegraph system may be reduced to this, in its essential elementary form, that it consists of a battery to excite the current, a wire to convey it, a means of interrupting and restoring it at will, and a magnetic needle to indicate its presence. All kinds of appliances are used to render the working more complete and expressive, but these are all only modifications of the outline arrangement,—battery, wire, needle, and commutator. This last word, commutator, is the name given to a small machine which enables me, by the movement to or fro of a small handle, to break or restore the completeness of the circuit.

(A.) *Battery.*—The battery, or source of power, may be any one of those already described, and the current that transmits the signals may be either primary or secondary—*i.e.*, it may be either the current excited by the battery, or one induced by that current in a second wire. One form of battery much in use is composed

of zinc and copper elements, moistened with very dilute sulphuric acid. Long submarine telegraphs are usually worked by secondary currents.

(B.) *Wire.*—The communicating wire is sometimes of copper, as being a good conductor, sometimes of iron, as being much cheaper. If iron be used, it must be galvanised—*i. e.*, coated with zinc to prevent it rusting; also the wire must be thicker than if of copper, because of its less conducting power. Especial care must be taken to prevent contact with any other conducting substance, which would divert the current from its proper route. For this purpose the wire is usually raised from the ground that it may be clear of contact, and supported upon poles. To prevent these poles themselves serving as conductors, the wire passes through small glass or porcelain tubes, which are attached to the posts to carry it. If, however, the wire pass under water or through the earth, this means of support is impossible. To guard, in this case, against contact with conducting matter, it is usual to encase the wire completely in some non-conducting material, such as gutta percha. Three or four wires are each covered with gutta-percha or yarn, and then the whole enclosed in a thicker casing, sometimes bound round for protection against injury with stout iron wire. But whatever be the structure, the inner wires alone are the conductor of the current; all the other parts are merely for their protection from injury, and to prevent the dissipation of the electric force.

(C.) *Signals.*—The ways in which the current may be made to indicate its presence are almost endless in number. A needle may be deflected to the right or to the left; a bell may be rung; marks of any length and in any number may be made on paper; or any combination of these and other signs may be used.

But in every case, a current passing along a wire is the cause of the indication. Let it be agreed that a deflection of a needle to the right shall express the letter A; a deflection to the left, the letter B; two to the right, C; two to the left, D; one each way, the letter E, and so on. I need not take the letters in the order of the alphabet, but take those most used, as the letters E, C, S, &c., to be expressed by the simplest signs. These signs being agreed to, I can express them by deflecting the needle to the right or left at pleasure. How can I do this? We have seen (p. 196), that a current in one direction deflects the needle to the right, and a current the reverse way deflects it to the left. I have only, therefore, to send a current past the needle, first in one direction, then in the other, and the needle is moved first one way and then the other. But can I do this with one wire? The wire itself will convey the current either way, but how shall I arrange it so that it shall convey it in both directions?

Let a wire, *w*, be stretched from the point A to a distant point P, and then, in a parallel line, back to B, which is close beside A. Also a battery, in working order, with short wires *a* and *b*. The

current passes, when these points are connected, from *a* the positive pole to *b* the negative. If now I connect *a* with A and *b*

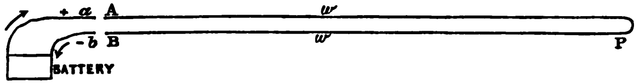


Fig. 127.

with B, I do join these poles, by means of the long double wire, and the current passes from *a* through A to P, and back through B and *b* to the battery. But if I, instead of this arrangement, join *a* to B, or *b* to A (which I can easily do by turning the handle the reverse way), the current passes from *a* through B to P, back to A, and through *b* to the battery again. So that I can send a current through the long wire A P B in either direction at will.

If now there be any number of small magnetic needles near this wire, they will be affected by the passing current, turning to the right or left according to its direction. And if, instead of placing the needles near the wire, I place them actually within the circuit, by using galvanometers (in which the wire carrying the current is coiled several times round the needle), the deflection is more decided, and therefore more appreciable.

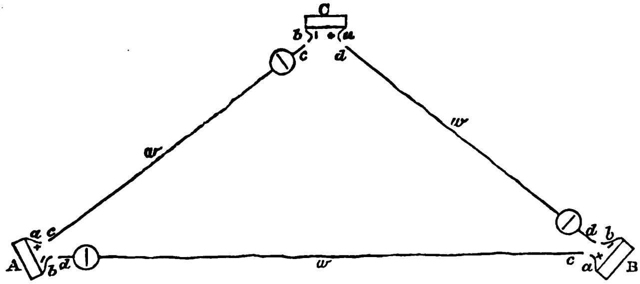


Fig. 128.

Let A, B, C be three telegraphic stations in a galvanic circuit. Each will be provided with a battery, a galvanometer, and a means of rapidly breaking and remaking the circuit, and of connecting, at will, any of the points *a*, *b*, *c*, *d*, with each other. If A desire to send a message to B, what is required is to take the whole circuit of wire as belonging to the battery A, so that a current passing from *a* (the positive pole), shall pass through the circuit, and return to *b* (the negative pole). This is done by connecting *a* with *c* and *b* with *d*, in which case the current passes in the direction A C B; or it may be done by connecting *a* with

d and *b* with *c*, in which case the current will pass in the direction A B C. Or, thirdly, I may send the current first one way and then the other, by joining first *a* with *c* and *b* with *d*, and then *a* with *d*, and then *b* with *c*.

While A is thus using the whole wire as belonging to his battery, what will be the relative positions of B and C? B is to receive the message, therefore his galvanometer must be within the range of the wire, but his battery will not be required. Therefore he will join *c* and *d*, so as to complete the circuit which will pass through the galvanometer, and let *a* and *b* be both clear of contact.

While A is thus communicating with B, what is C's relation to either or both? He sends nothing, therefore he does not want his battery; he has nothing to receive, therefore his galvanometer is not needed. Therefore he disconnects both, and is quite neutral to both A and B.

There may be any number of stations on a given circuit, but only one message can be sent at a time. One station can send the *same* message, at the same time, to every station on the line, and frequently does so. Thus, let there be any number of stations, A, B, C, D, E, F, &c. (each provided with a battery and a galvanometer), on the same circuit. Any one can communicate with any other, and all are prepared to either send or receive a message—*i.e.*, all the galvanometers and batteries are in readiness to be connected, or are connected. Any one, say C, has a message to send to F. He connects his battery, and sends a current throughout the whole circuit. This gives some signal, usually the ringing of a bell, at *every* station, and thus it is announced generally throughout the circuit that a message is about to be sent. By preconcerted signals it is also announced from whence it comes, and for which particular station it is intended. The attendant at F, the station to which the message is to be sent, makes such arrangements as may be necessary to send the current through his galvanometer, so that the deflections of its needle may deliver the message. At the intermediate stations, nothing has to be done, except that if the galvanometers be within the circuit they may be disconnected, so as to prevent the useless dissipation of force in acting upon them. If F desire to reply to the message, he must connect his battery with the wire, while C prepares to receive the message, the intermediate stations still remaining inactive.

But how is the bell rung which serves to call the attention of the stations? It will be noticed that the signals by which messages are communicated depend upon the power the galvanic current possesses of deflecting magnetised needles. Another set of results, of which the ringing of bells is one, depends upon another power of a current, that of magnetising soft iron. Let it be desired that a bell should be rung as a signal that a current is passing through the telegraphic circuit. Place an ordinary

small gong at the given place, and let the hammer be held back by a small catch, placing near the catch a bar of soft iron, so that if the soft iron were a magnet it would draw the catch aside, letting the hammer fall on the bell.

Now, if the wire carrying the current pass several times round the bar of soft iron, it will, whenever a current passes through it, be converted into a magnet. This magnet will instantly exert its newly-acquired force upon the catch restraining the hammer, and draw it aside. The hammer will fall and sound the bell. In this way a current passing through the wire at once announces its presence in a manner that calls attention by appealing to the sense of hearing, and so requiring less persistent attention than if the only signal were the movement of the needle, which, appealing only to the eye, would require continual watching for.

Thus, speaking generally, each station on an electric circuit requires a battery to send the current, a magnetic needle (or galvanometer) to express the signals, and a bell to call attention. These three instruments represent the three main discoveries of galvanic science: the development of a current, represented by the battery; the action of a current on a magnetised needle, represented by the deflections of the galvanometer; and the magnetic influence of a current on soft iron, represented by the machinery for ringing the bell.

Just as an ordinary highway is open to all passengers, each entering and leaving at any point, so the wire of a galvanic telegraph may be considered as the highroad, which each message enters and leaves at any point; but it is a road only wide enough for one passenger at a time.

The person sending the message requires to have the battery under his control, since it is necessary to reverse the direction of the current; therefore every station must have a battery to which the wires can be affixed. The person receiving the message requires to know in what direction the current passes, and when the direction is changed, and how many times the current is sent and discontinued. For this purpose he requires a galvanometer, which tells the presence of a current by its deflection, its direction by the manner of its deflection, and its cessation by returning to rest.

But the telegraphic systems do not in practice consist of a *circle* of stations, but of a *line*, such as from London to Liverpool, with other stations between. How, in this case, is the circuit to be established, since it seems essential that the current leaving the positive pole of the battery should return to it by the negative pole. There is one wire passes direct from one end to the other, and may then be turned round and brought back. There is no need for the wire to be arranged in a *circle*, or any definite form; all that is required is that there shall be a continuous conducting wire from the positive to the negative pole. It may be turned to and fro, pass round galvanometer needles again and

again, be coiled round soft iron bars (to magnetise them), or be taken in any direction; so long as there is no interruption of the wire between the two poles, the current will pass through all its windings and turnings.

But, practically, the method of completing the circuit is very different indeed from this. Only *one* wire passes from terminus to terminus, as in the submarine cables, and each end is *connected with the earth*, either by being fastened to some metallic pipes, such as gas or water pipes, or by being fastened to a copper plate of large size. It is found in practice that the current passes as readily along the single wire thus terminating in connection with the earth, as along the double wire. The usual explanation of this phenomenon is, that the earth itself is the continuation of the conducting substance. It is a bad conductor, but thick wires of bad conductors may have a power of conveyance equal to thin ones of good conductors. This is why the large plates of copper are fastened to the ends and buried in the earth, so that there may be a thick wire of earth terminating at each end in a copper plate, and so forming with the metallic wire a continuous circuit.

The parallel of this to the plates of a battery—*i.e.*, the zinc and copper plates that form the elements of the battery—will at once suggest itself. Just as the liquid in which they are immersed forms a continuation of the conductors, and carries the current, by means, as it were, of a wire of water, depending for its thickness upon the size of the plates; so the earth reaching from one of the buried plates to the other, forms a thick wire of earth, that makes up for the low conducting power of its nature by its great thickness as compared with that of the metallic wires, this thickness depending upon the size of the buried plates.

It is possible to conceive, however, that the earth does not act precisely in this way, but that it may act rather as a general reservoir of electricity. Thus, I pour in a pailful of water on one side of a pond, and another person takes out a pailful on the other side. I may be said to have passed a pail of water over to him, and practically I have. Again, I pay ten pounds into a bank in London, and it is drawn out in Dublin or Paris. Practically, I have sent ten pounds to Dublin or Paris, but not actually.

May it not be that, in the same way, the earth acts as a general reservoir of electricity? It does so in frictional electricity. This is one argument: and another, negative, argument is, that in the case of the plates of a galvanic battery, the liquid intervening is polarised, decomposed, and recomposed; but it is not certain that this is done in the case of the earth. Also, the distance between the plates is very small in one case, and there is no other body present; while, in the earth circuit, the distance between the plates may be hundreds of miles, and all kinds of breaks and interposed matter may occur. Still, it is the usually accepted theory that the earth does complete the circuit, making up for its lower power by its great bulk.

(13.) **Various Methods of Telegraphy.**—Assuming that we have now a correct, though only elementary, outline of the principles upon which the system of telegraphy is founded, it may be well to give attention to some of the special methods of operation. It is desirable, also, to notice if any special conditions are introduced by the great length of the conducting wires; and if so, what means are employed to subdue any difficulties thus created.

First, as to some of the special methods (1) of exciting the electric current. I have spoken of it as being usually a voltaic current, generated by the chemical action of a voltaic battery. But the motive power of a telegraphic system is very frequently derived from the action of permanent magnets upon conducting substances brought near them. If I cause a copper disc to rotate swiftly between the poles of a horse-shoe magnet, I electrify it, and if wires lead from this disc, a current will pass through them. This mode of exciting electricity is described more fully under the head of magneto-electricity.

Also, great use is made of secondary currents—*i.e.*, currents excited in one wire by its proximity to another (p. 205).

Here the primary exciting force is derived from a galvanic battery.

So that we may say that there are in use three methods of sending a current through a telegraphic wire:—

(A.) A primary current, derived directly from a battery.
(B.) A secondary current, derived from a primary as above.
(C.) A primary current excited by magneto-electricity.

The specialty of the first is simplicity; of the second, strength; of the third, persistency. The first is simple, requiring only a few plates of metal, a liquid, and a wire, but it is not so strong as the second, nor so persistent as the last. The second is stronger, because the number of coils can be increased at pleasure. In both these cases the battery has to be renewed at intervals. The third is more persistent; there is no battery to be renewed; the excitation is mechanical, not chemical.

(14.) **Various Methods of Signalling.**—Next as to the special modes of reversing the direction of the current, and of making and breaking it with rapidity as well as certainty. We have seen (p. 213) that what is wanted is a ready method of connecting either of two wires to the positive pole, and the other to the negative pole.

Now, let the two wires *a* and *b* be the wires of the battery, and *c* and *d* the two lines of the telegraph wire. Then what is wanted is to have an easy and rapid method of connecting *a* with either *c* or *d*, and *b* with either *d* or *c*. This might be done by simply holding the wires *a* and *b* in the right and left hands, and moving them in whatever way was required, for simple contact is all that is necessary. But, in addition to the connection of the battery

wires with the circuit, the connection of *c* with *d* is necessary, when the station is not sending a message; for if they be not connected, the circuit is not complete, and no signals can be sent by any other station.

We have then to consider how we can connect *c* and *d* in such a manner that the connection can be at once removed and replaced by the connection with the battery. One method is similar to the turn-tables employed on railways to move engines and carriages from one set of rails to another. Let there be a circular plate of some non-conducting material, working in a frame to the right or left by means of a handle in the centre. Let the wires *a b* from the battery be brought into contact with the frame of this plate, as shown in the figure, and let also the telegraph lines *c* and *d* be brought to it, one on either side. A line of wire crosses the plate from *c* to *e*, and from *e* to *d*. This wire terminates in small plates of metal at *c* and *e*, and a larger plate at *d*. When the handle is vertical, the communication between the wires *c* and *d* is complete, and signals can be passed, but the wires *a* and *b* are insulated by the non-conducting intervals *a e* and *b e*. By turning the handle

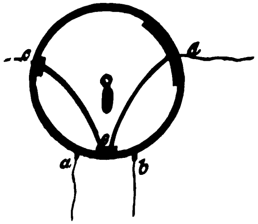


Fig. 129.

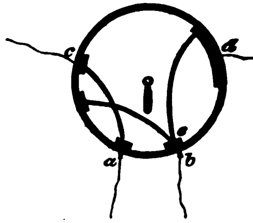


Fig. 130.

to the right, I turn the plate also in the same direction, and the wire and plate *e* comes into contact with *b*, so that the line *d* is connected with *b* (and therefore with the battery), but the connection between *e* and *c* is broken. But I want the line *c* to be connected with *a*, and so with the battery, so that the current can still pass from *c* and *d*, but through the battery. This is effected by means of another wire crossing the plate and terminating in plates so placed that when *e* is moved to *b* they connect *a* and *c*, and the current passes in the direction *a*—*c*—wire—*d*—*b*. The connection between *c* and *d* is now through the battery, and not across the plate.

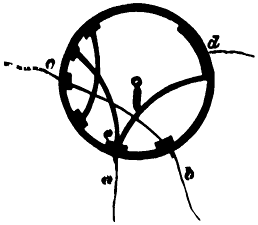


Fig. 131.

If I turn the plate to the left, the point *e* comes into contact with

a, and connects *d* with *a* (instead of with *b* as before), and again the connection with *c* is broken. But I want to connect it now with *b* (instead of with *a* as before), and this is done by a third wire crossing the plate and terminating in small plates so placed that when *e* is in contact with *a* they connect *b* with *c*, and so again complete the connection of *c* with *d* through the battery, but in the reverse way—*i.e.*, the current now passes in the direction *a*—*d*—wire—*c*—*b*. By "wire" I mean the whole length of wire between the two stations.

So that with this instrument I have only to turn the handle to the right or left to send a current to the left or right. By turning it first to the right and then to the left, I send two currents, one to the left and then one to the right. The exact distance the plate has to turn is marked by stops, that prevent it moving too far.

Fig. 129 shows the complete arrangement when at rest. The plate at *d* is longer than the other, so that whether the plate be turned to the right or left, it is still in connection with the wire *d*. A turn to the right connects *d* and *b*, and also *a* with *c*. One to the left connects *d* with *a*, and also *b* with *c*. When at rest *d* and *c* are connected, and *a* and *b* are both insulated.

Another method, precisely the same in principle, but even simpler and easier of comprehension, is to use a small rod of non-conducting material, terminating in metallic plates, to each of which one of the battery wires is fastened.

In fig. 132 the wires *c* and *d* are shown, terminating in stout iron springs, and connected by the cross-piece at the end of a *non-conducting* rod to which *a* and *b* are fastened. The rod is connected with both *c* and *d*, but *b* is connected with neither (since the rod *a b* is non-conducting), so that the current passes from *c* to *d*, or from *d* to *c*, and not through the battery.

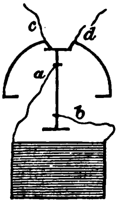


Fig. 132.

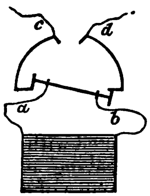


Fig. 133.

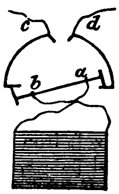


Fig. 134.

Now, let the rod, working upon a pivot in its centre, be turned by a small handle, just as the circular plate was. Fig. 133 shows us this position. Let it be turned to the right; one end of the rod is in contact with *c* only, the other with *d* only. Consequently the current passes from *a* to *c*, and returns from *d* to *b*, the direction being *a*—*c*—wire—*d*—*b*.

Turn the rod to the left: *a* is connected with *d*, and *b* with *c*, and the current passes in the direction *a—d*—wire—*c—b*. These connections can be made, broken, or reversed at will, and with great ease and rapidity.

(15.) **Various Signals.**—Besides the variety of methods of inducing a current, and of making the necessary signals, there is great variety in the signals themselves. The deflections of a magnetic needle are certain, easy to understand, and readily caused, but the signals so made are in no degree permanent. Another system of signals are in use that are permanent. To effect this, we use not the deflection of a magnet by the current, but the magnetisation of soft iron bars, by means of coils of wire surrounding them. This simplifies the sending apparatus, for all that is necessary is to send a current, either positive or negative, the signals depending for their meaning not upon the direction of the current, but upon the time of its continuance, and the number of times it is sent.

The line *a* of the battery and the line *c* of the circuit are brought nearly together, but separated by the interval *a c* of non-conducting material. The pivot *d*, the key *m*, and the stud *e*, however, complete the circuit when the key is pressed down, so that *e* and *c* are in contact; but when no pressure is on the key *m*, the spring keeps it up, so that the circuit is broken by the interval between *e* and *c*. When I want to send a current I press the key *m* down just as if it were a pianoforte key, and when I take away my finger, the circuit is broken by the spring pushing it up again, and separating *e* and *c*. I can therefore, in a most simple way, make the circuit complete as often, and for as long a time, as I think proper. This is the mode of sending the signals. How shall they be received and *permanently* recorded?

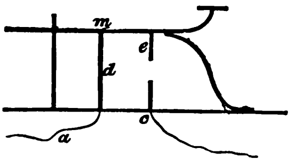


Fig. 135.

The contrivance for recording the signals takes the place of the galvanometer (which is not used), and consists essentially of a small soft iron bar, coiled round with fine wire, through which the current passes, and a lever having at its end a small projection, which is pressed against the edge of a wheel. If a strip of paper be coiled round this wheel, the projecting pin will mark it when the current passes—but only then. Thus the presence of a mark on the paper testifies the existence of the current, and the length of the mark (varying from a mere dot to a continuous line of any length) testifies to the duration of the current. Therefore, since by means of the pianoforte key the current is entirely under our control, we can mark, by its means, the strip of paper with any number or variety of dots or lines.

Let a and b be the wires coming from the distant station whence the message comes, and c d two upright bars of soft iron, round which the wires a and b are coiled many times. Just above these, and supported on an upright bar m, is a lever n, which is not in contact with c and d except when a current passing through the coils magnetises them, and they then draw down the lever n by their force. Since this lever works upon the fixed point m, the depression of one end causes the elevation of the other, and so the end r is raised (whenever the current converts c and d into magnets), and brought into contact with the wheel o, round which a strip of paper passes.

All things being in readiness for a message (*i.e.*, the lever n not being in contact with either the magnet or the wheel, and the

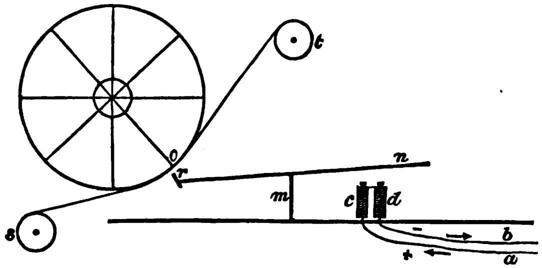


Fig. 136.

strip of paper being coiled round the roller s, with the end passing over the wheel o and fastened to the second roller t), a current is sent by the depression of the key m at the sending station. This completes the circuit: the current exerts its force in magnetising the soft iron bars c and d at the receiving station; these, by being magnets, draw down the one end of the lever n, this raises the other end r, which is then pressed against the wheel o. This wheel revolves, and so carries the paper past the end of the lever r, from the roller s to the roller t. The pressure on the key at the sending station being removed, the bars c and d cease to be magnets, the point r falls by its own weight (which is counteracted by the force of the magnets when it is raised), and the mark on the paper is no longer made. A succession of taps on the key of one station thus produces a succession of dots on the paper of another. If the key be held down, the dot becomes a line. In this way dots and lines may be made on the strip of paper at will. How can these dots and lines be made to express words, and so convey messages?

Let it be agreed that one dot shall stand for the letter e, two dots the letter i, three the letter s. These three letters occur most frequently, and therefore we will take the simplest signs for them.

In the same way we may express all the letters of the alphabet. Thus :—

.	*e*	. —	*a*	. — —	*w*	. — — —	*j*
. .	*i*	. . —	*u*	. — .	*r*	. . — .	*f*
. . .	*s*	. . . —	*v*	. — . .	*l*	. — — .	*p*
. . . .	*h*						
—	*t*	— .	*n*	— . .	*d*	— . . .	*b*
— —	*m*	— — .	*g*	— — . .	*z*	— — . —	*q*
— — —	*o*	— . — .	*c*	— . —	*k*	— . . —	*x*
— — — —	*ch*						

The numerals from one to ten may also be expressed in the same way. Thus :—

. — — — —	1	—	6
. . — — —	2	— — . . .	7
. . . — —	3	— — — . .	8
. . . . —	4	— — — — .	9
. . . . .	5	— — — — —	0

in which each dot expresses *one*, and each stroke *two*, if before the dots, but not after them or without them. Also, since five marks are used for numbers, and only four at most for letters, there is no fear of confounding letters with numbers.

(16.) **Relay.**—We have now to notice if any means can be used to increase the strength of a current that may be weakened through the length of the wires. We have seen (p. 191) that the resistance (r) of the wires is an important consideration in telegraphic systems, because of the great length. We know, in the case of the Atlantic and other telegraphic lines, that a current can do work after passing over a distance of even thousands of miles, so that it may seem unnecessary to seek for means of strengthening currents that prove themselves strong enough for the work required of them.

But there are practical conveniences in using two weaker currents in preference to one stronger one. But how are they to be connected? How can the force of one be made to set the other in action? We see that one current can be set in action by closing the circuit, as by means of the key just described. Now, if a second circuit can be arranged in readiness, it may be set to work in a similar manner by means of the first, if this first can be made to close the circuit of the second. This can be done by means of a small apparatus in which an electro-magnet draws down a lever and so closes the circuit. Thus: the wire through which the first current passes terminates in a coil round two soft iron bars *c c*. These being thus made magnets, draw down a small lever *d*. This is all the work the first current has to do. The second current passes along a wire *m n*, the continuance of which is along the upright *o*, the spring *s*, the lever *d*, and the second upright *t*. But this continuance is interrupted by the interval between *d* and

t. When *c* and *c* are magnetised, they draw down *d;* this joins *d* and *t*, and so completes the circuit. The one end of the lever being drawn down raises the other, but this is allowed for by the expansion of the spring *s*, which is still a complete conducting connection. The spring has also the utility of breaking the second circuit whenever the first ceases, because so soon as the bars *c c* lose their magnetic force, the spring contracts and draws down one end of the lever *d*, thereby raising the other, and separating *d* and *t*. The second current thus depends entirely upon the first, and in this way the weakened force of one current is made to set in action the stronger force of a second. The instrument by which this is done is called a *relay*. The action of a relay will suggest to some minds the sending of the "Fiery Cross" in the 'Lady of the Lake.' The messenger, worn out by fatigue, uses his little remaining strength to hand the cross and tell the message to his successor, who, fresh and strong, starts on his errand. So the relay, receiving from the first current just enough force to tell it what to do, sends out the same message with all the energy and velocity derived from a fresh battery.

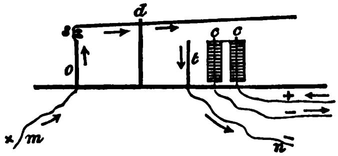


Fig. 137.

SUMMARY.

A TELEGRAPHIC system consists essentially of a *battery* to excite the current; a *wire*, to convey it; and a *galvanometer* (or some corresponding apparatus), to express the signals. Page 212.

The person sending the message requires to have control over the battery and the wires. The person receiving the message requires a recording apparatus, observed by himself, but under the control of the sender. Page 214.

Telegraph messages are conveyed by a system of signs agreed upon; these signs are given either by the direction of the current being changed at will, or by the number of times the current is sent, and by the length of time it is kept in existence. Page 217.

When the distance is very great, the current is used to excite a fresh current by closing the circuit of a second battery. This apparatus is called a **relay**. Page 222.

MAGNETISM.

(1.) **Introduction.**—An ordinary schoolboy's magnet has the power of attracting to itself light iron substances such as needles, pens, &c. Also of giving them a temporary power of the same kind, for one pen held by the magnet will attract another to itself. But if we compare this attraction with that shown by an excited glass rod for gold-leaf, feathers, &c., we shall find important differences to exist.

1. The magnet will continue to attract, and will not, like the rod of glass, first attract and then repel the same substance.
2. The attraction is only exhibited (perceptibly) towards some substances, and appears to be determined by the nature of the substance, not its lightness; for while an excited glass rod will attract any substance, and draw to it those whose weight it can move, a magnet attracts only iron bodies, and will move towards them if they be fixed and their attraction powerful.
3. Different portions of the magnet have different powers. Either end will attract an ordinary piece of iron or steel, but if a magnetised needle (which is itself a small magnet) be brought near a magnet, one end will attract the eye and repel the point, while the other will repel the eye and attract the point.
4. The magnet is always attractive. Its power does not require to be excited, and cannot be destroyed without the magnet itself be de-magnetised.
5. The attraction of a magnet cannot be insulated. It will pass through any intervening substance that does not counteract it. A needle resting on a table may be moved by a magnet held under the table

I take two bar magnets (*i. e.*, straight ones): I find that each end of either will attract any iron or steel bodies. If I suspend either of them by the centre, so that it is free to move without

friction, and free from any external attraction, it will gradually settle in a fixed position, one end pointing nearly north, and the other, of course, nearly due south. So also will any other magnet.

If now I mark the end pointing north with the letter N, and the other end with S, I shall be able to distinguish the extremities, and to speak of each with distinctiveness. By bringing the two ends marked N together I find a mutual repulsion. By bringing the two ends marked S together, I find also a repulsion. By bringing the N end of either to the S end of the other, I find a strong attraction. This resembles very much the attraction and repulsion of positive and negative electricity, with the important difference that there is no change—*i.e.*, that neither is capable of altering the condition of the other, but only of attracting or repelling it.

In either of the magnets I find that the attractive power is chiefly in the ends: it decreases as I pass towards the middle, and at the middle becomes nothing. Therefore I may infer that the middle of the bar is in a different condition to the ends, but it can easily be shown that this is not the case, and that every part of the magnet is in exactly the same condition. I take a magnet, and breaking it across the middle, find that I have two complete magnets. The broken ends attract, and are respectively S and N, as the other ends are N and S. These had no attractive force before, because they each neutralised the other.

I break each of these again in halves, and I find that I have now four magnets, all perfect and symmetrical; and I may go on breaking each in two, or any number of pieces, and shall find that each piece, however small, is a magnet, having a N. and a S. pole.

A bar magnet is straight, but if I bring its poles together, or nearly so, by bending it, I get what is called a **horse-shoe magnet.** But as this could not be done without heating it, which would destroy its magnetism, it is usual first to make the piece of steel the required shape, and then to magnetise it. This may be done either by passing the N. pole of a magnet over one end of it, and the S. pole over the other; or by placing a piece of soft iron across the ends (so as to make a ring of metal), and then to pass one pole of a bar magnet round and round the ring of metal several times.

Steel magnets when once made are permanent—*i.e.*, they retain the magnetic arrangement and magnetic power. But I can make a piece of soft iron, such as a poker or a steel pen, into a magnet, though only for a time, and during the presence of a permanent magnet. In steel the particles are moved with some difficulty, in iron very readily. But the steel magnet, when made, is permanent, the soft iron one only temporary.

In fig. 139 is shown a *horse-shoe magnet* with keeper *w*. The

greater part of the magnet is covered with sealing wax *s s*, the only uncovered part being *m m*, near the keeper.

The only difference between bar and horseshoe magnets is the difference of form. In all other respects they are the same. Magnets should never be left lying carelessly about. A horseshoe one should have its two poles connected by a piece of soft iron, called a *keeper;* bar magnets should be arranged in pairs, their poles reversed, with pieces of soft iron or keepers

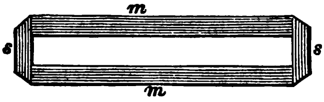


Fig. 138.

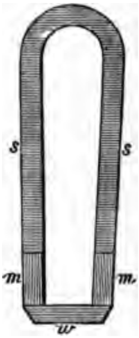


Fig. 139.

across the ends, so that each piece connects a N. and a S. pole. These pieces of soft iron are temporarily magnetised, and have N. and S. poles, which satisfy the attraction of the poles of the magnets, and so keep them from deterioration.

In fig. 138 is shown a pair of *bar magnets m m,* with the keeper *s s.*

(2.) **Effects of Magnetism.**—The presence of a magnet is shown by its attractive or repulsive power, by its power (in certain cases) of producing electric currents, and by its power of making permanent magnets of steel, and temporary ones of soft iron.

(A.) *Attraction and repulsion.*
(B.) *Production of electric currents.*
(C.) *Magnetism, permanent and temporary.*

The parallelism between these effects and those of electricity will occur to my reader at once ; as also will the points of difference when the two are compared.

(A.) *Attraction and repulsion.*—If I mix a quantity of small iron filings with sulphur, it will seem difficult to separate the two thoroughly. But a magnet held near will at once bring the iron filings together in groups, and with a very little trouble the two may be entirely separated. The magnet attracts the iron, but not the sulphur.

Iron exerts this magnetic force more powerfully than any other substance. Nickel may be magnetised, but with much less effect than iron ; so may cobalt, but with still less result. Steel alone seems to possess the power of retaining its polarisation so as to overcome the action of external objects. And, in like manner, steel, iron, nickel, and cobalt possess, in decreasing amount, the property of being attracted by magnets. Probably all bodies are

capable of polarisation, but in so weak a manner as to be very unstable. Practically, permanent magnets are only of steel, and temporary ones of soft iron; while it is chiefly on iron and steel that attraction and repulsion are shown.

The N. poles of magnets attract the S. poles of other magnets, and all non-magnetised iron. The S. poles of magnets attract the N. poles of other magnets, and all non-magnetised iron. The N. pole of one magnet always repels the N. pole of another. So also the S. poles of any two magnets are mutually repellent. Non-magnetised steel or iron is always attracted by either pole of a magnet. The power of this attraction or repulsion increases and decreases as the square of the distance decreases or increases. That is, magnetic power varies inversely as the square of the distance.

(B.) *Electric currents produced by magnetism.* — This is described fully under the head of **Magneto-electricity.** It will be sufficient to say here that magnetism by itself is not sufficient to produce electricity. It will be found that in all cases some other phase of force, usually motion, has to be associated with the magnet, which latter may be looked upon as arranging or polarising the force communicated to it. Just as when I throw a ball against a wall, the wall rearranges the force, and throws the ball in another direction. So when I associate motion with a magnet, the magnet rearranges it, and produces electricity.

(C.) *Magnetisation, permanent and temporary.*—The method of permanent magnetisation I have described under "Sources of Magnetism," and the phenomena of temporary magnetisation under "Induction." It will suffice here to say that with a magnet I can make a piece of *steel* into a permanent magnet, and a piece of *soft iron* into a temporary one.

(3.) **Sources of Magnetism.** — An ordinary piece of steel may be magnetised in several ways:—

(A.) *By another magnet.*
(B.) *By voltaic electricity.*
(C.) *By frictional electricity.*
(D.) *By the influence of the earth.*

It will, I think, be eventually found that these four are but subdivisions or phases of one influence: already we know that A and D are the same, and that B and C are but varieties of electric force.

(A.) *Magnetism by means of magnets.*—Any piece of steel may be made a permanent magnet; and any piece of soft iron may be made a temporary magnet. It is only necessary to polarise all the particles of an iron or steel bar to make it a magnet. In steel this is done permanently, when done at all, but in soft iron the magnetic state continues only for a time.

I take a thin strip of ordinary steel and pass it briskly over the end of a magnet, or, laying it on the table, I draw the end of a magnet several times over it, always in the same direction. It is then polarised, and possesses all the powers of a magnet—will attract iron, has a N. and a S. pole, and, in effect, is a magnet.

Another method, and a better, is to place the strip of steel between two magnets, so that they are all three in one straight line, with the magnets reversed, so that the steel to be magnetised has the N. pole of one magnet at one end of it, and the S. pole of the other magnet at its other end. I then take two other magnets, and putting the N. pole of one and the S. pole of the other together at the centre of the steel, I draw them away from each other towards the ends several times, and it is then a magnet.

If the steel be thick, a still more efficacious method is to place it as before, endways between two magnets, also placed endways, and in reverse order, and then, placing the other two magnets on it, but not quite together, being about an inch apart (with a piece of cork between them, so as to keep the distance the same), to draw them up and down the steel, both in the same direction, several times.

If I magnetise a piece of steel by passing one magnet over it, I am said to do so by the method of *single stroke;* but if I use two magnets, I am said to use the method of *double stroke.*

After I have magnetised a small needle or strip of steel, by contact with a magnet, I can demagnetise it by reversing the process. Thus, if I magnetised it by six strokes on a N. pole, less than six strokes on the S. pole will deprive it of all magnetic power, for it is easier to demagnetise than to magnetise; just as it is easier to demolish than to build up.

(B.) *Magnetism by voltaic electricity.*—A small needle may be magnetised by placing it within a coil of copper wire through which a current is sent. An ordinary sewing needle will be found to have become a permanent magnet if a copper wire be coiled some ten or twelve times round it, and a current from one or two cells be sent through the wire. I usually place the needle in a small test-tube, round which I coil the wire. Generally a steel bar will be polarised if it be placed at right angles to a wire through which a current passes, if the current be strong enough to affect the mass of steel. By coiling the wire round the needle the practical strength of the current is much increased.

(C.) *Magnetism by frictional electricity.*—In theory and in practice this is identical with the use of voltaic electricity. The usual method is to discharge a Leyden jar or battery by means of a wire, one part of which is coiled round the needle.

(D.) *Magnetism by the influence of the earth.*—Practically, the earth itself is a huge magnet, having N. and S. poles opposite each other. These magnetic poles are nearly the same as the geographical poles. At present the magnetic N. pole is some 20°

W. of the geographical, and the S. pole some 20° E. of the geographical S. pole. These relative positions vary year by year, and even day by day. But looking at the whole mass of the globe as a magnet, having N. and S. poles opposed to each other, and having exactly the same powers as an ordinary magnet, it is reasonable to expect it to act just as any ordinary magnet would. Accordingly, we find that soft-iron bodies are acted upon by induction, when favourably placed with respect to the poles of the great magnet called the earth. But as these are really examples of induction on soft iron, and not of permanent magnetisation, I have spoken of them under *Magnetic Induction.*

Loadstone.—But the power of displaying magnetism possessed by the oxide of iron called *lodestone*, may be referred to here. The property is due to the presence of iron in the earth so called, and probably arises from the strata of the earth having been for ages in a position with reference to the magnetic poles of the earth favourable to its development. I have spoken of this more fully in a later chapter.

(4.) **Nature of Magnetism.**—From this it follows that a magnetic piece of steel must be considered to be in a *polar* condition—*i.e.*, its atoms must be considered to be arranged regularly, so that the N. pole of each is in contact with the S. of the next, and its S. pole in contact with the N. pole of the next. In this way the attraction of each particle is satisfied and neutralised, excepting the outer poles of the end particles, which are attractive because they are not in contact with the corresponding poles of any other particles.

From this we may get a definition of a magnet. We may say that a magnet is a piece of iron, in which the particles are all arranged symmetrically as to their poles, so that the attraction of all the poles of all the particles are satisfied and neutralised (by contact with their opposites), excepting the outer poles of the particles at the two ends, which, not being so in contact, therefore remain attractive.

Just as frictional electricity has been explained by a theory of a dual fluid called electricity, so has magnetism been accounted for by the existence of a dual fluid called "magnetic fluid," and we have been told that when a piece of iron or steel is magnetised this dual fluid is decomposed, the positive being drawn to one end, and the other, or negative, being repelled to the opposite extremity. This theory has now even less vitality in its magnetic than in its electric form, and it is becoming the accepted idea that the attraction and repulsion are inseparable from the atoms of steel themselves. It may some day be seen that the whole world, and all that is in or on it, would be polarised but for the innumerable disturbing causes incessantly at work on it and around it; that the magnet is not the exception to the rule, but the remaining permanent type of rule.

(5.) **Induction of Magnetism.**—Soft iron may be temporarily magnetised by the contact, or even the proximity, of a permanent magnet. I bring a bar of soft iron near the pole of a magnet: it is attracted. If it be near the N. pole of the magnet the attracted end of the iron becomes its S. pole, and the other end its N. pole, its particles being polarised throughout. If I attach it to the S. pole of the magnet, these conditions are reversed. I can then, if the magnet be a good one, magnetise a second, or even a third, piece of soft iron in the same way. On removing the magnet, the polarity of the soft iron is at once destroyed (*i.e.*, the iron reverts to its original condition), and the attraction of each for the other no longer exists.

It is easy to tell the N. and S. poles of a magnet from each other, by means of any other magnet, since the N. poles of two magnets always repel each other, as also do the S poles, while N. always attracts S., and S. always attracts N. The most convenient form of *test magnet* is a small one, or compass needle, mounted on a small stand. This can be easily moved, and brought near any body whose magnetic condition it is desired to test.

Soft iron may be magnetised by induction (*i.e.*, may be polarised temporarily) without actual contact with a magnet. If two pieces of soft iron be put together on a table, they will show no attractive force; but if a good magnet be held over them, they will be, by its inductive force, polarised, and each will attract the other; but this ceases the moment the magnet is removed.

The presence of a powerful magnet is therefore evidenced by the temporary magnetisation of all soft iron near it. What, then, will be the effect of the great magnet called the earth upon iron bodies on its surface? Are they all magnetised? If so, every piece of iron would be a magnet, and we know it is not. The answer is, that every piece of soft iron that is at rest and free from disturbing influence, is magnetised by the earth's influence. Thus, I can magnetise a bar of soft iron by merely holding it with one end pointing towards the N. pole of the earth—*i.e.*, in the position it would occupy if the earth had acted upon it. (This will also illustrate the *inclination* and *dip* of magnets.) When held in this position the bar becomes really a magnet. I can assist this polarisation by tapping the end of the bar with a hammer. This probably loosens the particles, and leaves them free to be arranged. The lower end of the bar is the N. and the upper the S. pole. If I reverse the bar, the poles instantly reverse themselves, the lower end being always the N. Thus with an ordinary kitchen poker and a hammer I can easily make a temporary magnet. Fire-irons that happen to lie in the proper position for any length of time will be found to be polarised. All strata of the earth that slope towards the N. or S. pole, and contain iron, are all more or less polarised. This is probably the

explanation of the *lodestone* or *loadstone*, which is a natural magnet, though a weak one.

(6.) **Comparison of Magnetism with Electricity.**—Magnetism differs from electricity in that it cannot be insulated. A strong magnet will attract or repel another, or attract a piece of iron through almost any substance, and with almost, if not quite, as much force as if nothing intervened. Thus, a magnet will move iron filings, or affect a compass through wood, glass, or any substance but iron.

If I hold a sheet of glass between a large magnet and a small one, it has no perceptible effect on their condition; a thin sheet of iron moderates, very sensibly, the attraction; a thick sheet destroys it altogether.

Light passes through glass and horn, but is totally stopped by iron or wood (except in very thin pieces). Sound will travel through wood or iron, but not across a vacuum. Heat will pass through rock-salt, and partially through glass, but is almost entirely stopped by water. So magnetism will pass through any substance but iron. But it must not be supposed that the iron merely intercepts magnetism. If I interpose a plate of iron between a large and a small magnet, the influence of the one over the other seems destroyed, but it is really counterbalanced. The plate of iron becomes magnetised, and acts upon the small magnet as well as the large one.

Heat assists in developing electricity, but the reverse is the case with magnetism. If I heat a magnet, I weaken its power; if I make it red-hot, I destroy its attraction altogether. A magnet will not attract iron that is heated to a white heat. If I put such a piece of iron near a large magnet, it is not drawn to the magnet as it would be if cold, but as it cools, it comes gradually under the influence of the magnet, and when about a dull red heat it will probably be drawn to it, but the exact time at which the magnet will recover its power depends on the size of the ball and the strength of the magnet. The action of electric currents on magnetised bodies is described under the head of "measurement of galvanic force," but is even more naturally a subject of "magnetism." I have pointed out the most apparent differences between the effects of electricity and those of magnetism, but they have in common the property of attraction. If, when testing the force of a galvanic current by the deflection of a needle, I use a large magnet, and the current be passing through a fine wire, I find that the wire is moved if it be unable to move the magnet, but is itself capable of movement.

Because these experiments are generally made with small and freely-moving magnetic needles, it is usually said that the needle is deflected by the electric current; but it would be more philosophical to say that electric wires and magnetic needles tend to cross each other at right angles.

If, therefore, electricity and magnetism be both vibrations, as seems probable from some facts, it is also probable that these vibrations are in different directions, so that when both are in action and meet, they naturally arrange themselves so as not to interfere with each other. But it is more probable, I think, that the two are but different phases of magnetism, and that the arrangement, or polarisation, of the wire is at right angles to that of the magnet.

I group on one side heat, light, and actinism; on the other electricity, galvanism, and magnetism. The one group is distinguished by its properties of being reflected, refracted, and absorbed; the other by its property of attraction. This has suggested the idea that the vibrations of one group are in straight lines, and those of the other circular, or rather spiral, and that this accounts for the attraction and repulsion they exhibit for each other.

Of all these six forces (or varieties of one force, as they may be), magnetism is the most distinct in some respects, and the least so in others. In distinction from all the others it assumes a positive position with reference to the earth; but this is only because the earth itself happens to be a magnet, and not a necessary condition of magnetism in the abstract. There is no abstract reason, that we know, why the magnetic poles of the earth might not be in the E. and W., or in any other two opposite points.

Magnetism also is distinct from the other forces, in that it is not capable of conduction or diffusion.

(7.) **Method of Conferring Magnetic Power.**—Magnetism is most probably a polarisation of the molecules of the substance magnetised. Assuming every substance to be made up of small particles closely packed together, and all of equal size and weight, we may suppose each of these molecules to be a natural magnet, having at its opposite ends a N. pole and a S. pole. If these are arranged, as they would naturally (by their force on each other) arrange themselves, so that each N. pole is in contact with a S. pole, the whole body is magnetically at rest, because there is no pole, either N. or S., that is free.

When I magnetise a piece of steel, by stroking it with a magnet, I arrange all these molecules in the same direction, so that each N. pole is in contact with a S., and each S. pole in contact with a N., excepting at the two extremities, one of which is composed of a row of N. poles, and the other of a row of S. poles. These, having their attraction unsatisfied, affect any iron substances near them, by re-arranging their particles in a similar manner. Thus, if I put a needle pointways toward the N. pole of a magnet, the particles of the needle-point have their S. poles turned round towards the magnet; but if I hold it to the S. pole, then they are turned with their N. poles to the magnet.

This theory assumes that all the particles of any substance,

however solid, are free to move on their own axes—*i.e.*, that solidity is owing to the *attraction*, for each other, of the component particles, and not to contact only. Just as a needle or a pen will cling to a magnet, first by one point, then by another; so may the atoms of a solid body be considered as free to move round and round, yet each retained in its place by the attraction of the adjacent atoms.

I magnetise a piece of steel by drawing it a few times, always in the same direction, across the pole of a magnet. This may be supposed to arrange its atoms regularly. If I draw it again in the same direction as before, I strengthen its power, by turning any particles that may still be irregularly placed; but if I draw it once across the pole in the reverse direction, I disarrange the particles, since the more easily moved are immediately reversed, while those more difficult to move remain as before. In this way I may demagnetise a pen or needle already magnetised; but if I draw a magnetised needle several times in the opposite direction, I do not demagnetise it, but I reverse the position of all its particles, and, therefore, of its poles.

Two magnets put together so as to form a compound magnet, lose, instead of gaining, strength. Each seems to partially neutralise the other. If I want a powerful magnet, I may either put together several small ones, side by side, or I may magnetise a piece of steel of the required size. But it is found, practically, that it is difficult thoroughly to magnetise a thick piece of metal, and that a more efficient magnet is made by putting together several thin plates, each one being previously magnetised. The compound magnet thus made is not, however, so powerful as the magnets of which it is composed. Thus if three magnets will each support just one-third of a pound, the three put together side by side will not support one pound. This loss of power is especially apparent when magnets of unequal power are put together, and least so when there is least inequality.

(8.) **Deflection and Dip of Magnets.**—I take an ordinary sewing needle, and draw it several times across one of the poles of a magnet. It has now N. and S. poles, and if free to move will point nearly N. and S. It may be suspended by a very fine thread, or fastened to a small piece of cork and placed in water. If it be perfectly free to move, it will be found that when balanced (so that gravity has no effect on its position) it will not be horizontal, but will point with its N. pole downwards. Also, it will not point due N., but somewhat to the west.

These two deflections vary with the position on the surface of the earth. The more east it is, the greater is the deflection westward; so that a needle at Paris is less deflected than one at St Petersburg, but more than one at New York.

The pointing downwards increases as the needle is carried northward, but decreases towards the south. Thus a needle at

Paris would *dip* (as it is called) more than one at Alexandria, but less than one at Edinburgh.

A needle placed in the middle of Africa, of S. America, or at the southern point of Hindostan, would remain horizontal, being attracted equally by the N. and S. magnetic poles of the earth. North of these points, the N. pole of the magnet is attracted more powerfully than the S. pole, and is accordingly drawn down. Conversely, south of these places the S. pole is depressed. The line of "no dip" is not a straight line. It is called the "magnetic equator," and corresponds to the geographical equator, though it does not coincide with it, excepting in two places, where the two cross each other.

The deflection to the west is called the **declination of the compass**; the deflection towards the earth is called the **dip of the needle.** The cause of both is the same—namely, the attraction of the N. end of the magnetised needle to the N. magnetic pole.

A needle free to move on its axis would point due N. at Hudson Bay, Richmond, U.S., British S. America, the White Sea, the Caspian Sea, the Bay of Bengal, Bombay, or in the W. of Australia. The irregular line passing through these points (crossing, on one side, N. and S. America, and, on the other, Asia and Australia) is the *line of no declination.* At any point in this line the magnetic N. pole is due N.

Between these lines of no declination, the magnet turns E. or W. Thus, in the Atlantic, Africa, Europe, eastern part of N. America, and the Indian Ocean, the declination is W. In S. America, the greater part of N. America, Asia, and the greater part of Australia, the deflection is E.

If I place a large magnet at the N. side of a table, and a small needle on the table (on a cork in a basin of water), I can illustrate the declination by moving the needle to the E. or W. of the line crossing the table due S. from the magnet. Also by moving the needle N. and S. parallel to the line.

One magnet attracts another. So the earth, being a magnet, attracts all others, and by virtue of its vast size and power exerts an immense power over them.

If the N. magnetic pole were at the N. geographic pole, then all compasses (or magnetic needles) would point due N., and the *declination* (or deflection westward) would be 0°. In fact, the term would be unknown. But since the N. magnetic pole is to the west of the N. geographic pole, all compasses point westward. Therefore the more E. a needle is, the more it is deflected to the west.

Since the N. and S. magnetic poles have equal and opposite powers, a needle on the magnetic equator lies evenly between both, and, speaking popularly, is level or horizontal. But a needle nearer the N. than the S. has its N. pole attracted with correspondingly greater force. So a needle nearer the S. pole has its S. pole drawn down. At the N. magnetic pole, a needle would be attracted to the earth and stand vertical, with its S. pole pointing

upwards. At the S. magnetic pole these conditions would be reversed, the S. pole of the needle being drawn to the earth.

These two movements, the deflection to the west and the depression of one pole, are thus evidently due to one cause, the attraction of a great magnet of spherical form for the smaller magnets on its surface. If a globular magnet were made, and small magnetised needles placed on it in different positions, the *inclination* and *dip* of each might be clearly shown.

(9.) **Mariner's Compass.**—I mentioned just now that the poles of a magnet were called North and South, because a magnet, when freely suspended and free from external influence, sets itself in a direction almost exactly north and south. This is well known to be the case in the "**Mariner's Compass,**" which is nothing more than a magnet made and mounted with the greatest care and exactitude. Since it always points nearly north, it shows in what direction the ship is moving; but it possesses exactly the same property wherever it may be placed, as well on land as on sea. This is explained on the assumption that the earth itself is a great natural magnet, having its poles nearly at its northern and southern extremities, so that every other magnet has one pole attracted to the north, and the other to the south, by the force of this vast magnet.

The property that a magnetised needle possesses of always pointing to the magnetic pole renders it of exceedingly great service to mariners, as serving to point out the direction they are going when no other sign is apparent. In all weather, during the darkest night, the humble mite of steel will faithfully show the way across the waters of the ocean, and unerringly obey the laws of the wonderful property conferred on it.

But this very fidelity occasionally leads to apparent misdirection. A magnetised needle, free to move, sets almost N. and S. But another magnet held near will divert it from this position, the force of the small magnet close to it being practically greater than the force of the larger magnet, the earth, which is more remote. So a ship's compass, which would, usually, point nearly due N. and S., may be greatly deflected by any mountains containing much iron that are near it, or by the bed of the sea, in shallow water, if the earth contain much iron ore. So also the great quantity of iron in a ship, especially one plated with iron, causes much deviation in the position of the compass. Practically, the best method of restoring the needle to its normal position has been found to be the placing of masses of iron in its immediate proximity, so as to compensate the derangement caused by the iron of the ship.

The pole of any magnet so attracted to the north is, correctly speaking, the S. pole of that magnet; and the pole attracted to the geographical south, is its N. pole; but the fact of a magnet taking (when left to itself) a definite position was known long be-

fore the cause of this movement, and, naturally, the pole turning N. was called the *North pole*, and the pole turning S. was called the *South pole*. So that each pole of every magnet is, really, the reverse of what it is said to be.

In a common compass the declination only of the needle is made use of, not the inclination, or dip. In an ordinary mariner's compass the needle is fastened to the lower side of a circular card. The needle rests on a point, and is free to follow the magnetic attraction of the earth. As it moves it takes with it the card, which has marked on its upper face the N. S. E. and W. points and the intermediate points. The only thing a compass does is to show in what direction relatively to the magnetic poles of the earth the ship is moving. From this, aided by other calculations, the sailor finds his position on the earth. One would think that the inclination, or dip, might also be utilised for this purpose.

(10.) **Measurement of Magnetic Power.**—To compare the strength of two magnets, the simplest method is to estimate the power of each in the same manner. This may be done by noting the effect of each in bringing to rest a small needle made to oscillate near it. Set a needle in motion, and notice how many times it sways to and fro before one of the magnets held at a certain distance brings it to rest. If the other magnet, held at the same distance, does the same work in the same time, the powers are equal; if it take longer, it is less powerful; if less time, more powerful. The number of oscillations the needle makes in each case before coming to rest will serve as a measure of the strength of the magnet. Thus if one brings it to a standstill after twelve oscillations, and another in fifteen, then the power of the first is to the power of the second as fifteen to twelve.

Another method of expressing the power of magnets is to make an equation between the weight of the magnet and the weight it will sustain by attraction, by finding what multiple one is of the other.

A *magnetometer* is also sometimes used, constructed on the same principle as the *torsion electrometer*. A small magnet is repelled by one of two magnets held near it. If this small magnet be suspended by a thread, it may be compelled to remain near the large magnet by twisting the thread. If the other magnet offers a repulsion requiring the same number of turns to overcome, the powers of the two are equal. In fig. 140, *b* may be the small magnet suspended by the thread *a*, which is twisted by the handle *m*. The larger magnet may be *d e* (though it would be horizontal, not vertical).

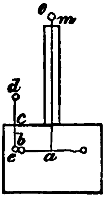


Fig. 140.

(11.) **Apparatus for Illustrating Magnetic Phenomena and Laws.**

A small horse-shoe magnet.

A bar magnet.
A small quantity of iron filings.
A few steel pens or other objects of small weight.

These can be had at a very trifling cost, say two shillings. With these it is easy to show some of the more commonly understood phenomena of magnetism, such as the attraction of iron objects by either pole of the magnet; the attraction of the opposite poles of two magnets, and the repulsion of the similar poles. Also the inductive power of magnetism. By the attraction of either pole of a magnet it will support the weight of any small object, say a steel pen. But this pen will itself support the weight of a second pen, and this second pen a third, and so on, according to the power of the magnet. Each pen that so supports another is, for the time being, itself a magnet, being made so by the power of the magnet over it. But this induced power lasts only so long as the original magnet is present. If I suspend a dozen pens in succession from a magnet, each is temporarily itself a magnet, but the instant I take away the magnet the pens fall away from each other, retaining nothing of their magnetic condition. To seek a moral parallel, we may compare the magnet, when acting inductively, to a moral leader in whose presence all men have their energies directed to some one object; but whose departure loosens the bond that keeps his followers together, and leaves them but a number of individuals, each one following his own ideas.

When only one magnet is used, it is better it should be the horse-shoe shape, because of the greater convenience in using an armature—*i.e.*, a piece of soft iron across the two poles. This cross piece, or armature, is made a temporary magnet, and strengthens the permanent magnet, by keeping it in use, and by preventing the disturbance that might otherwise take place in its polarisation, from the attraction of surrounding objects. The attraction of magnetism is the consequence of a certain atomic arrangement, and whatever preserves this arrangement, preserves the magnetic force.

Just as a student of languages might derive both rest and vigour from literature taken as a recreation, so a magnet is the better for being at work even when at rest, and this is what an armature does for a magnet. Bar magnets are usually kept in pairs, arranged alternately side by side, with two armatures, one at either end. Thus each armature connects a N. and a S. pole. But in a horse-shoe magnet, the two poles come close together, and one armature suffices.

(12.) For more detailed magnetic experiments, we want more and better apparatus,—

A pair of bar magnets.
A large horse-shoe magnet.
Iron filings, iron pellets, or any small iron bodies.
Electro-magnet; for this a galvanic battery is required.

The cost of these will be some £2 or £3.

It will be noticed that while we have electroscopes, electrometers, and galvanometers, for noting the presence and amount of electricity and galvanism, we have no simple instruments known as magnetoscopes or magnetometers; and but little reflection is wanted to show why this is. Magnetic force is at once perceptible by its attraction, and the amount of force present can be roughly estimated by the size of the bodies attracted, and the distance through which they move when attracted. Also the movements of the magnet, when it is capable of motion, are themselves indications of the presence of some disturbing cause.

Bar magnets.—Straight bars of steel that have been magnetised. The pair I use is about 12 inches in length, 1¼ inch in width, ½ inch in thickness. The quality—*i.e.*, the power—of a magnet depends upon the purity of the steel, its uniformity of structure, and the care with which it has been magnetised. Assuming that a magnet is a magnet because of the polarisation of its constituent particles, it follows that the presence of any other than steel particles, or of a variety of qualities of steel, will interfere with the full development of the magnetic force. But it must not be forgotten that this assumes after all the existence of magnetism as a *natural* force, since it assumes that every atom of steel has a N. and a S. pole by its inherent nature, and that the conversion of a piece of ordinary steel into a magnet is really only the arrangement of these minute natural magnets so that their forces shall not be mutually counteractive, but able to exert their power upon external bodies.

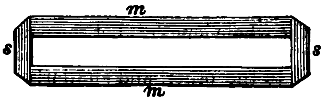


Fig. 141.

Fig. 141 shows two bar magnets with keepers. The magnets *m m* are reversed, so that the armatures *s s* connect the N. pole of one with the S. of the other. When so arranged, no magnetic force is evident, because each pole is neutralised by the other.

Horse-shoe magnet.—The one I use is made of three plates of steel screwed together. These bars when straight were 14 inches in length, ¾ inch wide, and ⅓ inch thick. So that the magnet, in its present form, is about 6 inches long and 1 inch thick. The three plates were magnetised individually before being put together. This is why it is in three pieces, and not of one thick piece, so that the middle layer may be more completely magnetised. In some magnets, the middle layer projects slightly beyond the others, and when there are 5 or 7 layers, each one projects more than the next outer and less than the next inner. In this way the centre layer is really the magnet, the others influencing that and strengthening it. The part of a horse-shoe magnet held in the hand is usually coated with sealing-wax as an insulator. Any given bar of iron will probably exert more magnetic force as a horse-shoe magnet than as a bar magnet, for the

reason that both poles act together, and the use of one strengthens the power of the other.

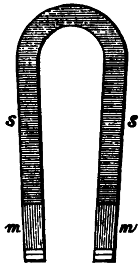


Fig. 142.

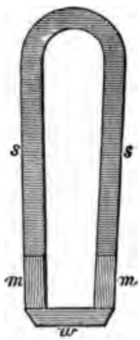


Fig. 143.

Fig. 142 shows a horse-shoe magnet, and fig. 143 shows a similar magnet, with keeper. The parts *s s* are covered with sealing-wax, to prevent any action through the hand, the parts *m m* being uncovered. The keeper *w* connects the N. and S. poles, and keeps the magnet at rest.

Electro-magnet.—Take a round bar of soft iron 18 inches long and 1 inch in diameter. Bend it in the form of a long horse-shoe, so that the two poles shall have a distance of some two inches between them. It has no magnetic power. Take a length of copper wire, about $\frac{1}{16}$ of an inch in diameter, and carefully wind round it fine thread, close together, so as to completely cover it, covering the whole with a coat of varnish, sealing-wax, or some other non-conducting substance. Then, just as the thread has been wound round the wire, wind the wire round the poles of the soft-iron bar. Let the threads of wire be close together, and wind it layer over layer until some twelve coverings of wire surround each pole from the extremity two-thirds of the whole length. Let the wire be continuous throughout, winding round first one pole with many close layers, and then passing over to the other, and similarly encasing that. Let the two ends of the wire project some foot from the iron, one end from either pole. All this being done, there is still no sign of magnetic power. But put the two ends in connection with a galvanic battery, one wire to each pole, and the soft iron instantly becomes a magnet of extraordinary power, far surpassing that of any permanent magnet of equal size. Break the galvanic current, all trace of magnetic power instantly disappears. Renew it, the soft iron is again a magnet, as powerful as before. Break and renew the circuit again and again at the greatest possible speed; however rapidly it may be done, so many times will the soft-iron bar cease to be, and become again, a magnet. These electro-magnets may be made of any size, and a large one possesses enormous power, sustaining even hundreds of pounds by its mere attractive force acting against gravitation.

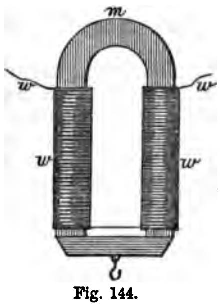


Fig. 144.

An electro-magnet is shown in fig. 144, consisting of the bar of soft iron *m*, partly covered with the wire *w w*, the two ends of which are connected with the battery. So that practically the legs of the magnet have the wire carrying the current coiled many times round them. A keeper connects the poles, but there is no magnetic force whatever except when the current is passing through the wires. Then and then only the bar of soft iron is a magnet.

Terrestrial Magnetism.

(13.) **Variations in Terrestrial Magnetism.**—In electricity and galvanism we set in action the power that we have to measure. But we have a vast natural magnet constantly at work, whose position and strength we may measure, just as we would those of any other magnet. Though we speak of the earth as a *natural* magnet, it is no more so than any other, except that the magnetising is by no means altogether independent of us.

By friction between glass and silk, between shellac and flannel, I generate electricity; by means of one magnet I make another of a bit of steel. By precisely the same means, only on a scale immensely greater, does the revolution of the earth and the consequent friction between the solid earth and the atmosphere, coupled with the action of the sun's heat, produce electricity and magnetise the earth. The varying position of the earth with regard to the sun, and the consequent variations of the direction of the forces in action, are doubtless the causes of the variations in the directions of the earth's polarisation, and in the resulting positions of the magnetic poles and equator. We have now to consider how these variations may be observed and recorded.

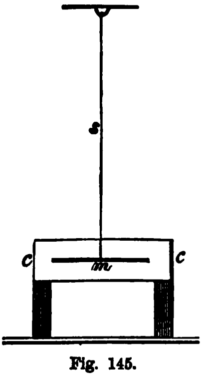


Fig. 145.

(14.) **Apparatus for measuring magnetic variations.**—A magnet *m* is suspended by a fine thread *s*, either from the ceiling or from some less movable support. I speak of a ceiling as movable because it is affected by every vehicle passing in the street, by every footfall on the floor. At Greenwich Observatory, where great steadiness is especially desirable, the magnet is suspended from the apex of a tripod formed by three beams of wood meeting at top, and resting, not on the floor (through which they pass without contact), but on the solid earth below. I once saw at a museum at Birmingham a huge giraffe standing, nominally, in the lower room, but whose long neck passes through the

room above, and whose head "crops up" (to use a geological expression) through the floor of a third room. So this tripod, resting on the basement, supports in the room above a magnet that is thus free from any effects of vibration caused by the shaking of the floor or ceiling.

Another example of the means by which absolute steadiness is obtained is shown in fig. 146, where the object is to get a *perfectly* level surface of mercury. To effect this a hole is dug in the ground, and filled with loose rubbish *o o*; on this a framework *n n* is erected; from this is suspended, by indiarubber straps, a second framework *m*; from this is suspended, in like manner, a third framework *e*; from this is suspended, by straps, a box *d*, which contains the mercury. The "incoherent rubbish" *o* (to use Mr Airy's name for it) and the straps serve as so many springs to prevent any motion of the ground to disturb the box *d*; and the practical result is a perfectly level and steady surface of mercury. The object of this is to obtain a reflection of the light from a particular star. The ray of light coming from the star *a* passes through a small opening in the roof and reaches the mercury *d*, from which it is reflected to the mirror *c*, and by that to the eyepiece *b*. The fact that by looking through *b* I can see the star *a* in the mirror *c*, is a striking instance of the laws of reflection of light.

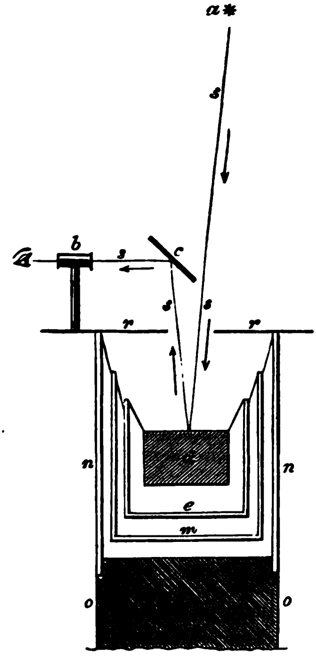


Fig. 146.

To return to fig. 145. The magnet being thus suspended is enclosed by a box *c c* resting on wooden supports, which serves no other purpose than to prevent the currents of air in the room from moving the magnet to and fro. At one end of this box is an opening protected by a glass plate. At the end of the magnet near this opening is fixed a small mirror, which of course moves with the magnet.

(15.) **Method of recording magnetic variations.**—We have now two questions to ask. (1) What will affect the magnet so as to move it? and (2) How can this motion be observed and

recorded? Let us first consider the second, and assuming that the magnet does move, discuss how we may observe and record the motion. If I place near the opening in the box *c* a small light *o*, it will shine through the opening, and, falling on the mirror at the end of the magnet, be reflected back through the opening. As the magnet moves, so will the mirror; as the mirror moves, so will the reflected ray of light. So that if I place a small screen to receive this ray, its varying position will show the movements of the magnet. But it would be tedious to watch and impossible to remember these movements, which, besides, are sometimes so small as to be almost imperceptible. Photography suggests a method that saves the trouble of either observing or trying to remember. The reflected ray of light falling upon paper properly prepared tells its own history. In fig. 147 is shown a more simple example of this method. I desire to know the variations of a thermometer *t* during some given period. I place on one side of it a light *c*, and on the other a sheet of prepared photographic paper, wound on a revolving roller *a*. The light passes through the tube *t* above the mercury, but not through the mercury. The paper is blackened where the light falls on it, and the rise and fall of the lower edge of the blackened part show the rise and fall of the mercury. The revolution of the roller brings a fresh part

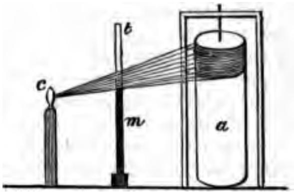


Fig. 147.

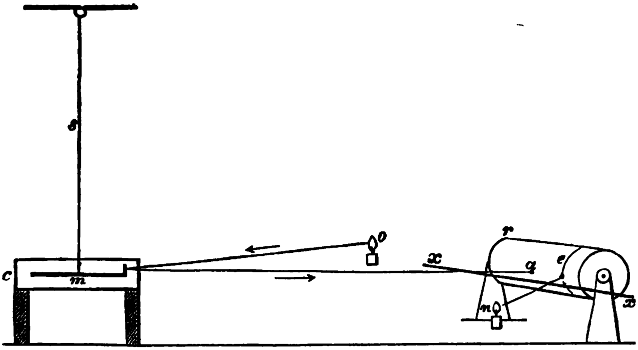


Fig. 148.

of the paper before the light, and vertical marks show the time of any particular variation. Precisely the same method is shown in *fig. 148, where the* purpose is to record the move-

ments of the magnet *m*. A light *o* falls upon the mirror fixed on *m* and is reflected to the roller *r*, where it records its presence and position by a black dot *a*. Since the light shines constantly, and the roller revolves continuously, this dot becomes a line, whose variations indicate the movements of the magnet *m*. But light radiating from the mirror as centre would spread over the whole surface of *r*, which is at some 8 or 9 feet distance. To prevent this I place a prism, *x x*, near the roller, and the light is by this refracted to a point. If I placed the roller nearer, the variations would be too small to show clearly the differences in degree of the movements of *m*, and also the very small movements would be not perceptibly recorded at all. A fixed light *n*, shining directly on the paper, makes a *base line e*. This line is always the same, and serves as a standard from which to measure the movements of *a*.

(16.) **Causes of magnetic variations.**—Having now seen how to detect and register the movements of the magnet, we come to the first question, What will cause these movements? The magnet is not affected by any vibrations of the building or of the air around it; in fact, is protected from all influence except that of the earth itself acting as a magnet. But we know that a magnet is affected by the earth in two ways: one called the *declination* or horizontal movement; the other the *dip* or vertical deviation.

Still we might reasonably ask whether these varied from day to day? Whether any daily or hourly movement could result from these? The magnetic poles of the earth being the points towards which all magnets point, and this pointing being the cause of the *declination* and *dip*, how could there be any change in the position of a magnet unless the poles of the earth themselves moved?

The reply to these questions is, that the poles of the earth *do move*, and are constantly moving; that they are not tangible objects, such as a cape or an island, but rather effects of several causes, varying in amount and position from day to day, and even from minute to minute. Just as in a theatre the eyes of the audience concentre now on this actor, now on that, now on a third; just as in Parliament, first this speaker, then another, then a third, becomes the centre of interest; just as a crowd is swayed to and fro by successive objects of interest; just as attention centres in the affairs, now of France, now of Russia, now of Germany, as each becomes the scene of especial political action,—just so the centre of magnetic attraction, the spot of greatest magnetic action, is continually shifting, though within narrow limits. The world is not a mass of magnetised steel, but a conglomeration of innumerable constituents, in which magnetism is induced or disturbed by the varying action of the forces causing, and resulting from, its axial revolution and its passage through space. These mighty movements are faithfully registered by our humble bit of steel suspended by its silk thread; its slightest motion, right or left,

betokens a movement of the magnetic pole towards the geographic pole or the equator; the slightest rise or fall of its mirror betokens a decrease or increase of the strength of the magnetic pole towards which it points. In the way I have shown it is possible to obtain correct records of every variation of the *declination*, the *dip*, and the *force* of magnetic attraction. At Greenwich Observatory there are three sets of apparatus, one for each purpose. In essentials all are as described on page 243. For the declination, or *horizontal* variations, the roller r is horizontal also; but for the dip, or *vertical* variation, the roller is placed upright.

(17.) **Apparatus for measuring variations in the strength of Terrestrial Magnetism.**—For the *amount* of magnetic force a somewhat different arrangement is necessary. The object is to test any change in the *force* of attraction shown by the magnetic pole. This will not be shown by either a horizontal or a vertical motion, since it is not the change in the *position* but in the *strength* of the pole that is to be measured.

It is therefore necessary that the magnet should be so placed that any *variation of strength* in the pole shall move it, but that any *change of position* shall not.

When meat is being roasted, it is necessary for it to be continually turning upon its own axis. This is sometimes accomplished by very primitive machinery—a fork and a piece of worsted yarn. The fork being stuck in the mantelpiece, the meat is suspended from it by means of the worsted. This is then twisted by the fingers a number of times, and by this means a torsion force is given to the string which keeps the meat in revolution for some time. But if, after twisting the string, I hold the meat still to prevent it turning, it is stationary under the influence of two equal forces.

By similar means I can place my magnet so that it shall show by its motion the variations of the magnetic force. I suspend it by a string as before, and twist this string several times. I now place the magnet E. and W., so that while the torsion of the string acts in one direction, the magnetic attraction of the earth, tending to set the magnet N. and S., acts in the other. The magnet is now stationary, held by two equal forces. The string pulls the magnet one way, the earth pulls it the other; the two forces are equal, because I twist the string until the torsion force equals the magnetic force.

If now from any cause the magnetic force becomes increased, it is stronger than the torsion force, and the magnet is moved by this extra force; but this movement twists the string more tightly until the increased torsion equals the increased attraction. If, on the other hand, the magnetic force is decreased by any cause, then the torsion force, being the stronger, unwinds the string and moves the magnet until the decreased torsion equals the decreased at-

traction. It is usual to suspend the magnet, for this purpose, by two threads (*i.e.*, bifilar suspension) attached to two points in the magnet. This gives increased torsion, and also prevents any dipping of the magnet.

By the same method, with such alteration in minor points as is necessary, we are able to record the time and degree of any variations in the declination, dip, and attractive force of any magnet at any given place. Three strips of paper, each having an irregular dark line, and having at the top the name of the place and the date, record these alterations of position and force of the magnetic poles, and can be referred to without doubt at any future time.

(18.) **Magnetic Apparatus at Kew Observatory.**—At Kew Observatory, until now under the direction of Mr Balfour Stewart, a neater and more comprehensive apparatus does the same work.

The three magnets, one arranged for declination, one for dip, and one for strength, are placed so that the lights are reflected to-

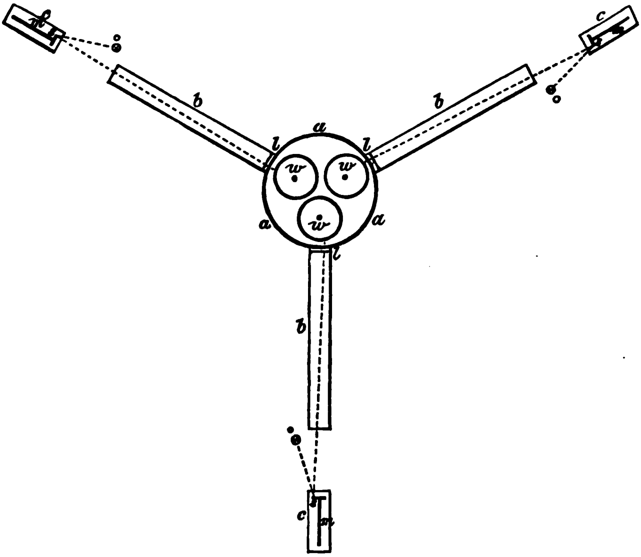


Fig. 149.

wards a common centre. At this centre are placed the three revolving rollers *w*, each opposite one of the three tubes *b*. At the end of each tube is a lense *l* to converge the rays of light to a

point. The three magnets *m* are shown in three cases *c*, and the mirrors at *s* reflecting the light from the flames *o*. The three drums *w* are enclosed in a case *a*.

In fig. 148 there is a second light *n* which describes a base line *e*, serving as a standard for measurement. But in fig. 149 there is no such second light, the base line being attained by a very simple method. The mirrors *s* are in two pieces, one piece fixed to the magnet, the other suspended above it by a string, so that the two halves make a complete mirror when the magnet is at rest. But the upper half remains stationary, while the lower moves with the magnet. Thus the same light *o* serves to describe the base line by means of the upper half of the mirror, and the line of variation by means of the lower half.

It is necessary to take care that no iron shall be used in any part of the apparatus, which is composed chiefly of wood and copper. The revolving drums *w* are turned by clock-work.

SUMMARY.

A magnet attracts iron. associated with *motion* it produces electric currents: it can also magnetise steel. Page 227.

Magnetic force is derivable from a magnet, voltaic force, frictional electricity, and from the magnetism of the earth. Page 228.

Magnetism seems to consist of the polarisation of the atoms of the magnetised body. Page 230.

Soft iron possesses induced magnetism when under the influence of a magnet. Page 231.

Magnetic force decreases with heat, and cannot be insulated. Page 232.

Magnets point towards the magnetic poles, which are *not* due N. and S. From this follows the *declination* and *dip* of magnetic needles, of which the compass is an example. Page 234.

The earth itself is a vast magnet, having poles that are movable within limits. Page 241.

By suitable apparatus we are able to measure the variations in force and position of these poles. Page 241.

DIA-MAGNETISM

CONSIDERED AS A PHASE OF MAGNETISM.

(19.) **Dia-Magnetism as a Phase of Magnetism.**—We have seen that an ordinary magnet attracts steel pens, needles, knife-blades, and, in fact, any iron or steel bodies whatever, though it may not be able to move them. But if I place a magnet near a quill pen, a pin, or a paper knife, I find no attraction whatever. It seems to follow from this that magnetism is confined to iron and steel.

But this, like most hasty conclusions, would be very far from correct. We might as reasonably suppose that because a small magnet will move a steel pen, but not a pound weight, therefore only the pen and not the weight is affected by magnetism. It is very important not to limit our ideas too much by our senses. What we see and hear is but a very small portion of the phenomena of nature.

I increase the power of my magnet until I have what is called a "strong magnet." But this is a general term. What is a strong magnet? Usually an electro-magnet. The one in use at the Royal Institution is an electro-magnet, consisting of a bar of soft iron some 4 or 5 feet in length, and 4 or 5 inches in diameter. This is doubled into the horse-shoe form, so that the poles are 6 or 7 inches apart. Round these are coiled many folds of wire, to within 3 or 4 inches of the poles, and to a thickness of 2 inches, making a total thickness of core and wire of about 7 inches. To bring the poles into closer proximity, two pieces of soft iron, about 6 inches long, are placed one across each pole, and can be brought as closely together as may be required. These are, by induction, magnetised, and form practically parts of the magnet. So that the poles can be kept at any distance apart, from actual contact to 6 inches. Such a magnet as this, when excited by a powerful battery, can support considerable weights, and shows an attractive force not only for steel and iron, but for other substances that, when we use only a small magnet, appear to be quite free from magnetic action.

Thus, when tried by a powerful magnet, not only iron, but also nickel and cobalt, appear to be subject to magnetic action. So also do antimony, bismuth, copper, lead, silver, mercury, and some other metals, as well as glass, phosphorus, sulphur, sealing-wax, wood, and many other non-metallic substances.

But there is one very striking difference between the two groups into which all these substances may be divided. Thus, of metals—

A.		B.	
Iron,	Platinum,	Antimony,	Lead,
Cobalt,	Palladium,	Bismuth,	Silver,
Nickel,	Manganese.	Copper,	Mercury.

All these are affected by a magnet, if of great power; but the metals in group A in one manner, and those in group B in another. I take a small bar of each, say 2 inches long, and $\frac{1}{4}$ inch thick each way. Suspended between the poles of a magnet, each of the bodies in group A will be attracted and reach *across from one pole to the other*, in the manner of a keeper. But those of group B will be repelled, and tend to set themselves *across this line, at right angles to the line a keeper would take.*

Therefore we may say that all substances are affected by magnets, more or less, but in one of two different ways, the members of one group being attracted, of the other repelled; one set taking up an *axial* position, the other an *equatorial*. By *axial* is meant the line joining the poles, by *equatorial* the line crossing this at right angles. Across the poles is *axial*, parallel to them is *equatorial*.

It seems from this to be necessary to revise our ideas of magnetism. If the action of magnets on bismuth or antimony had been discovered before the action on iron, this equatorial setting, or repulsion, would have been called magnetism. There is nothing in the name to limit it to one set of phenomena rather than to the other. The attraction of a piece of iron by a magnet, and its repulsion of a piece of bismuth, are equally magnetic. Therefore, scientifically, the term magnetism is used to cover all the effects of magnetic action, those of attraction being called *para-magnetic;* those of repulsion *dia-magnetic*.

MAGNETISM.

PARA-MAGNETISM	DIA-MAGNETISM
Attraction	*Repulsion*
Axial-position	*Equatorial position*

If I use a single-bar magnet instead of one of the horse-shoe form, I get simply attraction and repulsion by either pole. Iron, cobalt, &c., are attracted; bismuth, antimony, &c., are repelled. The axial and equatorial positions are simply the results of attrac-

tion and repulsion. In the case of a bar magnet, *either* pole attracts iron and repels bismuth; in the case of a horse-shoe magnet, *both* poles attract the same piece of iron and repel the same piece of bismuth.

So that it is not the axial and equatorial positions, but the attraction and repulsion which we must consider, if we desire to comprehend dia-magnetism.

(20.) **Nature of Polarisation by Magnetism.**—The action of an electro-magnet on iron is much greater in degree than on other substances, and we must therefore examine this as likely to show us most clearly what its exact nature is. We say that a magnet *polarises* the atoms of any substance it attracts, by which we mean that all these atoms are arranged orderly in the same direction. Thus, a regiment of soldiers is standing on the parade-ground, in groups, each man standing in the position and attitude that suits his convenience. At a given signal all these groups are rearranged; all the men face in one direction, and stand at equal distances from each other. Every man's face has the back of another man turned to it; every back has a face towards it, excepting only the first faces and the last backs. If we compare the faces of the men to the N. pole of a magnet, and the backs to the S. pole, then the regiment of soldiers are the exact parallel of a magnet.

In precisely the same manner a piece of soft iron has its atoms in groups until the attraction of a magnet rearranges them, and draws all their N. or S. poles towards itself. But this assumes that the atoms of soft iron are themselves veritably magnets, having N. and S. poles, and that all the magnet does is to polarise or arrange them.

Some acute reader may possibly think that this may be capable of verification in this way; unless all the atoms are exactly spherical in shape, any such polarisation must affect the length and thickness of a bar of iron. For if the length of the magnets be greater than their width and thickness, then when they are all arranged endways there must be an increase of length. And this is true. A bar of soft iron, when magnetised, *is* lengthened at the expense of its thickness. But the increase is so very small that in any one atom the difference between the width and length must be not only inappreciable, but literally inexpressible.

(21.) **Dia-Magnetism a polar force equally with Magnetism.**—This being true of magnetised bodies—that magnetism means the polarisation of their molecules, and a consequent lengthening—we might reasonably ask what corresponding phenomena are presented by the action of a magnet on bismuth? Does a bar of bismuth or of antimony undergo the same action of arrangement or polarisation as a bar of iron? If so, is its length altered?

In reply, there seems to be but little doubt that dia-magnetism is as truly a polar force as para-magnetism; that the atoms of bismuth are as really polarised as the atoms of iron, and that these atoms have N. and S. poles in precisely the same manner. One experiment, upon which much of our belief in the polarity of dia-magnetism rests, is to place an astatic needle between two bars of bismuth, so that any action one might have would be neutralised by the other. To do this I place two bars of bismuth parallel, suspended endways (like two clock-weights) over a wheel by a cord. When they are quite level I place the needle across them so that the two bars and the needle form the letter H. By using two coils of wire, one round each bismuth bar, I subject them to the action of two electric currents in different directions, so that they will have their poles reversed, *if any polar force be developed*. Whatever such force be developed the needle will not show its presence, because its position across the middle of the bismuth magnets causes the action of each pole to be neutralised by the opposite.

By means of the cord joining the two bars, I raise one, thereby lowering the other, until the upper end of one and the lower end of the other are level and opposite the astatic needle. Now, since the currents are contrary, so will be the poles of the bismuth magnets. Therefore the upper end of one and the lower end of the other are both N. or both S. Therefore the needle is acted on by a double force, each part of which helps the other to deflect it. If the bismuth bars be really magnetised, the needle will be deflected; if not, there will be no movement. It is found that the needle *is* deflected, though only slightly, and that an equal deflection in the contrary direction is produced when the bismuth bars have the other pair of poles brought into action.

Thus the two bars are parallel and opposite, with the needle across their middle points, and no current passing through the coils. All is still. I send a current round each bar, one each way, and lower the right-hand bar, thereby raising the other. The needle is deflected one way. I reverse the bars, raising the left and lowering the right, the deflection is the other way. From this it follows that the action of the bismuth upon the needle is the same as would be the action of soft iron under the same circumstances, and that this polarity is the result of the electric current. It would be interesting to perform this experiment first with bars of bismuth, and then with bars of soft iron, all other things being the same in each case. We have now the reply to our first question, Is a bar of bismuth or antimony polarised in the same manner as iron? We may say that it is, though the degree of force so developed is very small as compared with the magnetic force of iron.

To the second question, Is the length of diamagnetic bodies altered in the same way as when iron is magnetised? We can only

say that, like the magnetic force developed, the change, if any, is very small; in fact, entirely inappreciable.

Dia-magnetism differs from para-magnetism in some points; in others it resembles it. One is weak, the other is strong; one repels, the other attracts; both are polar forces; both are developed by electricity. Clearly, therefore, the difference between them is one of degree or variety, but not of kind. Weakness and strength are comparative; attraction and repulsion opposite phases of the same force.

Various theories have been suggested to account for these differences, most of them assuming the existence of a magnetic fluid. It might be worth while to bear in mind that we use one kind of magnet in all our experiments; namely, steel magnets, or else soft iron acted on by electric currents. If in frictional electricity we had never used but glass and silk for its production, it is questionable whether our knowledge of it would not be more limited than it is; so it may be that a series of experiments with magnets made of bismuth might serve to enlarge our ideas on the nature of dia-magnetism, and as to its relation with para-magnetism.

(22.) **Dia-magnetism of Liquids.**—The differences to our senses between solids, liquids, and gases are palpable and familiar; and it is difficult to realise the fact that for many scientific purposes the solid, liquid, and gaseous states of a substance are almost alike; that it is more important to consider the nature of the particles of a body than their degree of cohesion. Thus liquids are as truly magnetic as solids; some being para-magnetic, and some dia-magnetic.

We estimate the magnetism of a solid by suspending a small bar of it between the poles of the magnet: how shall we estimate the magnetism of a liquid? One method is to enclose it in a tube suspended as before. The tube acts as though the liquid were a solid bar, setting axially or equatorially according as it is para- or dia-magnetic. Another method of testing whether a liquid be dia-magnetic, is to place two cross-pieces of soft iron on the poles of an electro-magnet so as to bring them close together, but of course not in contact, and to place a small watch-glass resting partly on each. A very small quantity of the liquid is then placed in the glass, and the magnet charged by a current. If the liquid be magnetic, it will be attracted by both poles, and will be higher at the sides nearest the poles, by reason of the attraction tending to draw it into two heaps. If it be dia-magnetic, it will be repelled by both poles, and consequently higher at the middle, and lower at the sides.

Either method requires delicate apparatus, strong magnetic power, and careful manipulation. The attraction of iron for iron under magnetic influence is strong, but of all other substances weak, in most cases very weak. One method of recording the attraction or repulsion of a liquid, when placed in a watch-glass

over the poles of a magnet, is to let a ray of light pass from above downwards through the centre of the liquid and glass. If the magnet attracts the liquid, the thickness is less in the centre; if it repels it, the thickness is greater in the centre. In the one case the refraction is greater than the other, and by means of a mirror placed below this can be ascertained, and proves a delicate test of attraction or repulsion where the amount is very small.

(23.) **Dia-magnetism of Gases.**—I cannot suspend a gas by a string, nor fill a watch-glass with it; and though I could fill a test-tube with it, the quantity contained would be so small as to be useless. I must therefore find some other method of testing the influence of magnetic action on gases. One method is to fill soap-bubbles, and notice whether they are compressed or protracted when passing between the poles of the magnet. A more complete plan is to deliver the gas from the mouth of a tube between the poles, and to place over this mouth three other tubes, one vertically above, and two others, one on each side of this, close to it at bottom, but diverging at top.

If the gas be dia-magnetic, it will be repelled by both poles and pass up the middle tube; but if it be magnetic, it will be attracted by both poles, and pass through the two outer tubes. But how shall its presence be detected? I place in the mouth of the delivery-tube a piece of paper moistened with ammonia, and in the two outer tubes paper moistened with hydrochloric acid. If the gas pass through the central tube, it continues invisible; but if it pass through the side tubes, the ammonia is carried into contact with the acid, and chemical action results, which is shown by the fumes given off.

A third plan is to let a beam of electric light pass between the poles and on to a screen. The gas, though invisible under ordinary circumstances, will throw more or less shadow on the screen; and by this shadow its motions, whether of attraction or repulsion, can be seen.

(24.) **Causes affecting Dia-magnetic Polarity.**—Electricity is increased by warmth; magnetism is increased by cold. In the same way dia-magnetism is influenced by change of temperature. It is also affected by the proximity of magnetic or dia-magnetic bodies. Thus if I mix two powders, one magnetic and the other dia-magnetic, into a paste, and suspend a cake of this paste, it will set axially or equatorially according to the quantity and strength of each constituent. Each will exert its full power, and the balance of strength on the part of the stronger will determine the position.

(25.) **Nature of Dia-Magnetism.**—As might be expected, the consideration of the "causes affecting dia-magnetic polarity" suggests what may probably be the nature of the force called dia-

magnetism, and in what it differs from magnetism, commonly so called—*i.e.*, para-magnetism.

If I use a steel magnet, iron sets axially, and bismuth equatorially. If I could use a bismuth magnet, probably bismuth would set axially and iron equatorially. So that all we can say is, that polarised iron attracts iron and repels bismuth, while polarised bismuth would probably attract bismuth and repel iron. Therefore there seems to be some radical difference between the polarisation of iron and of bismuth.

It might be thought that simply the poles were reversed in the two metals; but this cannot be the essential difference, because the magnet determines the arrangement and direction of the atoms of both the iron and bismuth. Magnetism is not the arrangement of iron or bismuth particles by themselves, but their polarisation by a magnet. Assuming that iron and bismuth atoms have naturally N. and S. poles, the presence of a magnet would arrange either in the same way. But the iron does not appear to attract either pole of the bismuth.

So that whatever arrangement constitutes the polarisation of bismuth, it is certain that repulsion is an important element of it. It might be, that whereas a magnet attracts by its N. pole the S. poles of iron atoms, because its attraction for these S. poles is greater than its repulsion of the N. poles, so iron repels bismuth, because its repulsion of the one pole is greater than its attraction for the other. We know that an iron magnet repels iron even while it attracts it, but that the attraction for one pole is greater than the repulsion of the other. So it may be that iron attracts bismuth even while it repels it, but that the repulsion of one pole is greater than the attraction of the other.

But iron may be seemingly repelled, and bismuth seemingly attracted. A small bar of iron, say the size of a small piece of slate pencil, will set axially when suspended between the magnetic poles, while a bar of bismuth will set equatorially; but if I compass these two bars into two flat plates by subjecting them to pressure, I find the bismuth sets axially and the iron equatorially—*i.e.*, the bismuth disc is attracted to the poles, and the iron disc sets parallel between them. How shall we reconcile these apparent contradictions? It may be that the compression caused the N. and S. poles to set *crosswise* in both the iron and the bismuth, so that the contradiction is only apparent, not real.

That this is so is shown by further experiments, which lead us to modify our statement of what is meant by magnetism and dia-magnetism. By *axial* and *equatorial* we do not necessarily mean that the iron or bismuth shall point any given way with respect to the *length* of any given piece as a whole, but that the N. and S. poles of the constituent atoms shall be *axial* if the substance be *magnetic*, and *equatorial* if it be *dia-magnetic*. It is quite possible that the compression of iron or bismuth into a flat plate may also have the effect of setting the N. and S. poles of the

metal across the thickness of the plate, which would at once account for the apparently exceptional behaviour of the plates.

In crystals, where *cleavage* is an element to be considered—*i.e.*, where the body may be considered as being made up of an indefinite number of very thin laminæ or leaves—we have other apparent contradictions: thus some magnetic crystals set equatorially, and some dia-magnetic crystals set axially. But on minute investigation it will be found that the cleavage of a magnetic crystal is axial, and the cleavage of a dia-magnetic crystal equatorial. But the magnet cannot attract or repel *cleavage*, which is only a series of spaces between the leaves.

This behaviour of crystals, however, coupled with that of compressed substances, suggests another line of thought. In both cases it is the *line of greatest compression* that sets axially in magnetic, and equatorially in dia-magnetic, substances. The line of cleavage is also the line of greater density, because in that line we have a continuous lamina or plate; but in the other line, across the cleavage, we have alternately leaves of substance and intervals of space, however small.

In speaking of the polarity of bismuth (p. 251), I said it would be interesting to experiment on soft iron and bismuth alternately. In 1854, Professor Tyndall did this in a very elaborate manner, and with very interesting results. His apparatus consisted of two electro-magnets and a coil of wire, within which, but free to move, were suspended first a small bar of soft iron, and, secondly, a small bar of bismuth. This amounted to really two large electro-magnets, and one small one—the small one having sometimes a core of iron, sometimes one of bismuth. By means of the coils round the magnets I can make the poles N. or S. at pleasure.

I place the two large magnets end to end, and then move one a few inches sideways from the other, thus, , and suspend the smaller one across these neighbouring poles N. somewhat thus . I have thus one end of the small bar near one magnet, and the other end near the second magnet. As might be expected, the N. pole of the large magnet attracts the S. pole of the small one, and *vice versa.* Also, the S. pole of the large magnet attracts the N. pole of the small one, and *vice versa.* I determine the N. and S. poles of the small bar of iron by the direction of the current passing through the coil within which it is suspended. I now replace the bar of iron by a bar of bismuth, and find I can affect its magnetic condition by means of the currents, just as I did the condition of the iron; but with the important difference, that the bismuth is attracted where the iron was repelled, and repelled where the iron was attracted.

Taking this experiment by itself, the result might be described by saying, that whereas a current of electricity passing round a

bar of iron made the left-hand extremity the N. pole, and the right hand the S. pole, these results were reversed in the case of bismuth, the N. pole being to the right, and the S. pole to the left. The coil and electric current being the same, the results of its action upon iron and bismuth are just reversed.

This would at first suggest a simple explanation of dia-magnetism, but it does not suffice. For if I present a piece of soft iron and a piece of bismuth to a powerful magnet, I might reasonably expect that both would be attracted (though probably with different force), since the N. pole of the magnet would attract the S. poles of both iron and bismuth, without reference to the side of an electric current on which they would be found. But we know that this is not the result.

To sum up, we may say,—

(1.) Iron and bismuth are both polarised by an electric current, but the relative positions of the poles are reversed.

(2.) Iron and bismuth are probably both attracted and both repelled by a strong magnet; but in iron the attraction overcomes the repulsion, in bismuth the repulsion overcomes the attraction.

(3.) The magnetic poles of both iron and bismuth have a tendency to set in the lines of greatest compression.

SUMMARY.

A magnet attracts cobalt and nickel, but with much less force than iron: it also repels bismuth, antimony, copper, and many other substances. Page 248.

Probably every substance is affected by magnetic force. Page 249.

The repulsive action of a magnet is called dia-magnetism. Probably the attraction and repulsion are two phases of one force. Page 250.

Liquids and gases are affected by magnetism equally with solids. Page 252.

By attraction and repulsion of magnetism is meant, not the attraction and repulsion of a given body as a whole, but of the atoms constituting it. Page 254.

MAGNETIC-ELECTRICITY.

CONSIDERED AS A PHASE OF MAGNETISM.

(26.) If I pour water into a basin, a jug, or any other vessel, it immediately assumes the form of the vessel. Heated metal is in the same way impressed with the contour of any hard substance in contact with it. In these instances the *form of matter* depends upon external influence.

If I throw a ball against the wall, the force with which I impel it is, as it were, rearranged by the wall, and the ball sent in a different direction; here not the *form* of matter but the *direction of its transfer* is altered by an external influence.

If I send an electric current through a wire which is wound round a bar of soft iron, this iron becomes a magnet: here is, as a result of external influence, a *transfer of force*, not of matter, from the wire to the iron, and from the iron to any smaller bodies upon which it may exert influence.

If I use my strength to turn a wheel upon a fixed axis, it would at first appear as if I not only wasted my time but had also found a way of *destroying* force, which is considered to be indestructible. All my labour would seem to produce no result, as neither axle nor wheel would be moved from its place. But if I place a band round the wheel, I can by this means communicate the force to a second wheel, at considerable distance even, and can move machinery; in fact, can do work. Even if I do not transfer the force to a second wheel, still it is not *destroyed*, though it may be *wasted*. That part of it is used in overcoming the resistance to the motion offered by the air, is easily shown by setting a wheel in motion first in the air, and then, with the same force, in a vacuum. It will be found that the same wheel will revolve for a *much* longer time when in the vacuum, free from the friction of the air, showing that much of the force is used in overcoming this friction. It is true that the wheel does not have to remove the air out of its way, because it continues to occupy the same space; but the air, being elastic, presses against the sides and edge of the

wheel, and so tends to prevent its motion. As an example of this, this month (October 1870) an aeronaut, conveying letters from the besieged city of Paris to Tours in a balloon, was fired at repeatedly by the German besieging army, and though the cannon-balls fell so far short of the balloon that he felt no uneasiness, yet the balloon was very perceptibly shaken by the force that was communicated by the balls to the air.

(27.) **Derivation of Electricity from Magnetism.**—Just as a vessel gives an outward form to water poured into it, just as molten metal can be stamped into any required shape by outward pressure, just as an electric current rearranges the particles of soft iron, so a magnet will rearrange a force that comes within its influence.

If I turn a copper disc on a spindle, and have fastened to it a copper wire, the other end of which is attached to a galvanometer, I shall find no trace of electric force; but if I bring near it a strong magnet, I find that I can affect the galvanometer by the force with which I turn the disc. This phase of energy is called **magneto-electricity,** or electricity developed by means of magnetism. The opposite of this is **electro-magnetism,** or magnetism developed by means of electricity.

It follows from this that I can develop an electric current without any of the complicated apparatus of voltaic battery and chemicals, by the simple process of turning a wheel on an axis in the presence of a permanent magnet. But though we get rid of the cumbrous voltaic machinery, we require apparatus of another kind, and perhaps as complicated. It is not sufficient to twirl a copper disc on an axis, and hold a magnet near it.

The copper disc must revolve either between the poles of a horse-shoe magnet, or parallel to the plane of a bar magnet—*i.e.*, across the direction of the keeper—in either case. The position of the axis of the disc is the same as that of the keeper. When I turn the disc I cause the development of electric action in the disc; and if I place one end of a wire on the axis, and the other end so that it presses on the edge of the disc, I can deflect the needle of a galvanometer by means of the current passing through the wire. The direction of the current depends upon the direction of the revolution. If the disc turns in one direction, the current passes from the centre to the circumference, thence by the wire back to the centre. If I turn the disc the other way, the current passes from the circumference to the centre.

(28.) **Theory of Electricity derived from Magnetism.**—One explanation of this action is, that a magnet has an electric current circling round it, just as the coil of wire surrounds the soft iron bar in an electro-magnet, and that the revolving disc cutting these currents is influenced by them. Another is, that the magnet is perpetually polarising the atoms of the disc, and that this

arrangement, being as perpetually disturbed by the revolving motion of the disc, produces an electric current.

The latter of these explanations derives additional force from another set of experiments, in which the keeper itself revolves upon its central point, in front of the magnet, each end passing from pole to pole in a continuous circular movement. In fig. 150 the keeper is a simple bar *w*, but in a magnet arranged for the keeper to revolve, not only *w* but *m m* would be the keeper—*i.e.*, the keeper would have two projections, one to fit each pole of the magnet. These small poles *m m* are coiled round with wire after the manner of electro-magnets.

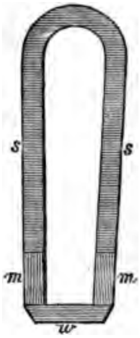


Fig. 150.

When the keeper is across the poles, it is itself a part of the magnet, its soft iron particles being polarised. When it has moved through half a revolution, this polarisation is reversed. When it has completed one revolution, the original polarisation is restored. Each end of the keeper is first N., then S., then N., then S. again, and so on continuously. It is N. when in contact with the S. pole of the magnet, but S. when it passes to the N. pole, then N. again when it returns to the S. pole, and so on.

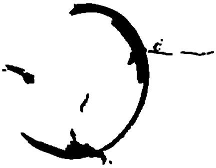
When the keeper stands across its normal position, free from contact with either pole, it will be quite free from any polarisation; and this will happen twice in every revolution, so that the keeper is first polarised in one direction, then depolarised, then polarised in the reverse direction, then again depolarised. These four changes take place every revolution, and the revolution may be performed many times in a second.

(29.) **A Continuous Current derived from an Induction Series.**—The currents thus generated in the keeper will be conducted by the wires coiled round the projecting parts of it. But they will be perpetually reversed in direction by the changes in the keeper. Can this be neutralised in any way, so that a continuous current can be produced?

We have seen (page 218) how, by the use of such apparatus as is there described, called *commutators*, of which figs. 151 and 154 show two specimens, we can reverse at will the direction of an electric current. By similar contrivances we can convert our double magneto-electric currents into one continuous current in one direction only.

If *a b* be the wires from the keeper, the current will pass through these in alternate directions as rapidly as the keeper is rotated, there being two currents for every revolution. If *c d* be the wire through which the continuous current be required to pass, it is only necessary to change the connection as often as the direction of the current in *a b* changes.

... b, as in fig. 151. a and b are not in con- ... Let the current be passing through



... 151.

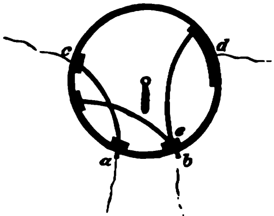


Fig. 152.

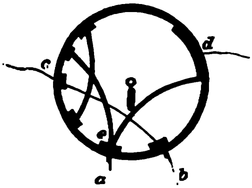


Fig. 153.

... direction of a to b, then if a be connected with c, and ... (fig. 152), the current will pass through $b\ d\ c\ a$. When ... current is reversed in $a\ b$, so as to pass from b to a, the ...angement in fig. 153 will enable the current to pass in the ... $c\ a\ d\ e\ b$. In both cases the direction in the wire $c\ d$ is in the ...ection $d\ c$. So that a succession of alternate currents in $a\ b$ ...oduce a continuous current in one direction in $c\ d$. Really it is ... succession of currents following each other with such rapidity as ... be practically continuous.

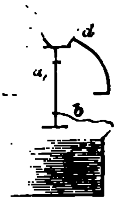


Fig. 154.

Fig. 155.

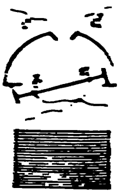


Fig. 156.

Figs. 154, 155, and 156 show another form of commutator. Here, as before, $a\ b$ is ... ... fig. 154 ... joined to c and b to d (fig. 155), or a joined to ... and ... fig. 156). The

commutator in general use for magnetic electricity is exactly on this principle, but not in this form. It usually consists of a non-conducting spindle on which the keeper revolves, and on which are placed several conductors, which do the work of changing the connection at every change in direction in the induced current.

The use of the commutator in telegraphy (page 218) is to obtain alternate currents in *c d* from a direct continuous current in *a b*. In magnetic electricity we obtain, by the use of a commutator, a direct continuous current in *c d* from alternate currents in *a b*.

(30.) **Apparatus for Magnetic Electricity.**—In this there is great variety, and often considerable complexity. But in principle all are as here described, consisting essentially of some good conductor revolving near the poles of a magnet, so that currents shall be induced and disturbed continually—induced by being close to the magnet, disturbed by being moved from it. We must consider each part of the revolving plate by itself, or we may consider the plate as a wheel made up of an infinite number of spokes. Each spoke will come to and depart from the line in contact with the magnet, and will be thus gradually magnetised and demagnetised. At the moment of its polarisation the force will be communicated to the wire, and this way each succeeding spoke will keep the wire in action.

The wire has one end in contact with the centre of rotation, and the other in contact with the edge. But the communication between the outer edge and the wire must be one of sliding contact only, for otherwise the wire would be wound round the wheel on its axle. In this way the wire acts as a conductor to each successive radius forming the wheel or plate.

Any number of magnets and of revolving plates may be connected so as to form a magneto-electric battery. The construction of these is often very complex.

SUMMARY.

Force spent in turning a wheel on a fixed axis is not destroyed, though it may be wasted. Page 257.

If a magnet be near a revolving plate of conducting substance, the force spent in causing the rotation will be construed into an electric current. Page 258.

This is caused by the successive polarisation and depolarisation of each atom of the plate as it passes the pole of the magnet. Page 258.

From these alternate induced currents a continuous direct current may be obtained. Page 259.

The apparatus for magnetic electricity is usually somewhat complex, but may all be resolved essentially into the action of magnets *upon revolving* conductors. Page 260.

THERMO-ELECTRICITY.

(1.) **Introduction.**—I take a hoop of copper wire and hold one part of it in the flame of a candle, or any other source of heat. By degrees the whole hoop becomes heated, the heat travelling round it on either side. I now insert a piece of antimony in the hoop, by cutting out a piece of the copper wire, which I replace by the antimony. Heating the point of junction, I find I have done more than send a current of heat round the wire. If I place a magnetic needle near the hoop (or connect it with a galvanometer) I get evidence of a galvanic current that did not previously appear to exist when the hoop was of one metal only. What are the different conditions introduced by the insertion of a piece of antimony into the circle of copper? Why should the passage of heat develop electricity in one case and not in the other?

The answer to this is, like the answers to most questions in natural science, of a twofold character. First, the reply is, that the difference in the conducting powers of the two metals and in their specific heats causes the electric current. I heat one part of a copper hoop, and place a delicate galvanometer at the opposite side. No deflection of the needle takes place; not because there is no force acting on it, but because there are two equal forces. Whatever effect the heat transmits round the hoop in one direction, it transmits also an equal and opposing force in the other. How then do we know that any force whatever is transmitted, since there is no evidence of its existence? That there is such a force may be shown by disturbing the equality of the two forces, and allowing one to act more than the other upon the measurer of force, the galvanometer. I take away a portion of copper on one side of the lamp, and replace it by an equal amount of bismuth. The conducting power and specific heat of bismuth are not the same as those of copper, therefore the heat passing from the lamp to the galvanometer on one side through copper only, is not exactly counterbalanced by that passing on the opposite

side through copper and bismuth, and the result is, the greater of the two forces deflects the needle of the galvanometer.

But if the influence of the bismuth be merely a mechanical one, might not the same result be attained by other means? If the bismuth merely retards the passage of the heat, might not the same result be attained by inserting an *additional* piece of copper, as by replacing copper by bismuth? If the bismuth accelerates the passage of the heat, will not the same result be attained by removing a part of the copper? To prove this I might simply move the lamp towards the galvanometer either on the right or left, so that the heat has to traverse a less distance on one side than on the other. I do this, and a faint evidence of galvanism is the result. I twist the wire a few times on the longer side, so as to interpose more resistance to the passage of the heat, and the movement of the needle is increased.

(2.) **Derived from Heat.**—From this it would appear that two unequal currents of heat opposed to each other produce the result to which we give the name of an electric current; and that the bismuth inserted in the copper ring causes electricity by its interference with the equality of the currents, and not as a distinct effect. So that electricity would seem clearly to be connected with heat.

But if electricity be thus produced by two unequal currents of heat, it should be stronger as this inequality is increased. Might it not also be reasonably expected to be strongest when this inequality was greatest—*i.e.*, when the weaker current of heat was altogether suppressed?

Thus I place the source of heat (say a gas flame) on one side of a copper hoop, and the galvanometer on the other side. But little, if any, electricity is evident. I interpose some substance on one side, so as to make the two currents acting on the galvanometer unequal, and I find that the needle moves more and more as I increase this inequality. But suppose I remove one side of the hoop altogether; ought not the current to be still stronger? But it apparently ceases to exist, and the result is simply conduction of heat from the gas flame to the needle.

This brings us back to the question—What effect can be produced by heat passing round a metal hoop which could not be produced by its passage along a simple rod of metal? Thus, I attach one extremity of a length of copper wire to a galvanometer and heat the other by a flame. At the same time I take another length of wire, and fasten both ends to another galvanometer, so as to make a continuous hoop of copper, which I heat (at the point opposite the needle) by a flame of equal power to the first one.

The single copper wire conducts heat to the galvanometer, but does not produce any signs of an electric current; neither does the double wire of the hoop, so long as the light and galvanometer are opposite to each other, having equal lengths of wire on either

side. But when I move the flame on one side nearer to the needle, or if I interpose any comparatively bad conductor, the needle is at once deflected. Assuming heat to be vibration, and electricity to be arrangement, how can this be explained ?

The heat travels from the lamp along the wire towards the galvanometer until it comes into contact with the foreign substance interposed. This is supposed to be a bad conductor of heat. What does this mean ? Is it not that the vibration does not travel so rapidly along it ? This is probably because of the greater difficulty in setting the atoms in motion. The heat will, therefore, accumulate at the point of junction. What will be the effect of the accumulation ? Partly to raise the temperature, but partly also it will tend to arrange the atoms of the body.

The ordinary apparatus, fig. 157, used for the production of thermo-electricity is the "thermo-electric pile," composed of a

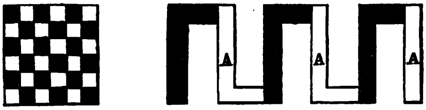


Fig. 157.

number of pieces of bismuth and antimony, so that a current of heat passing through the battery has to pass from bismuth to antimony, and from antimony to bismuth again and again. This repeated interruption, accumulation, and conversion of heat produces an electric current, and this may be made evident by the use of a magnetised needle or galvanometer. If a wire be fastened to either extremity of the battery, and connected with the galvanometer, the needle is deflected whenever the junctions of the bismuth and antimony are heated or cooled.

Why bismuth and antimony are used will at once be apparent from the following table, which gives the order of power in a battery of this kind.

Bismuth.
Platinum.
Tin.
Lead.
Gold.
Copper.
Silver.
Zinc.
Iron.
Antimony.

Any two of these metals being used as elements of a thermo-electric battery, the one standing higher in the list here given would be positive to the lower one. Thus, tin is positive to gold, gold to copper, silver to iron, &c., so that necessarily bismuth and antimony, being the extremes of the list, will, when coupled, give the strongest current.

The similarity of the reasoning here and in the case of the elements of a galvanic battery is at once apparent. In the case of the development of electricity by chemical affinity, the affinity of a metal for oxygen determines its place in the table. In the case of development of electricity by heat, what is it that determines the order ? Why is bismuth at the top, and antimony at the bottom of the list ? I will try to *answer this* question in the final chapter.

RADIATION.

(1.) **Introduction.**—Radiation is the giving off, in all directions, of heat, light, sound, &c., and depends upon the surface rather than nature of the radiating body. In a perfectly dark room I bring together the carbon points of an electric lamp, and then slightly separate them. Instantly a bright light is produced, which spreads throughout the room, reaching to every point of the walls, ceiling, or floor that is not hidden by any non-transparent body; and even if any such substance prevent the light from reaching directly any part of the wall or ceiling, yet the part so hidden from the light is not perfectly dark, for the light bends round the screen more or less. If I enclose this electric light in a box having an opening (say a foot square) on one side, the light will pass out through this, radiating as before. If I place this box near the wall, I produce on the wall a light of a foot square; if I withdraw the box from the wall, the illuminated space enlarges, but the light becomes less bright. When the distance from the aperture to the wall is equal to the distance from the light (*i.e.*, the carbon points of the lamp) to the aperture, the lighted space on the wall will be 2 feet each way, or 4 square feet in size, but the light will be much less bright than before. The surface illuminated will be four times as great, but it will be lit up with only one fourth the degree of brightness. As I draw the box still farther from the wall, I light up a still larger surface, but less brightly.

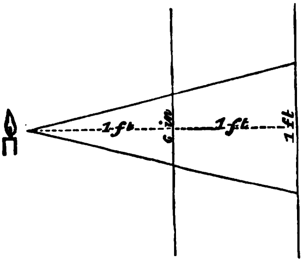


Fig. 158.

Fig. 158 shows a source of light shining on a screen at 1 foot distance, and on another at 2 feet. The light that covers a space 6 inches square on the first screen, illuminates less brightly a space 12 inches *square* on the second.

(2.) **Law of Inverse Squares.**—Just as any given quantity of water will cover a small surface more deeply than a large one, so a given quantity of light will light up more brightly a small than a large surface. And this is true whether light be a vibration or a real substance. Assuming the truth of the theory that it is but a vibration, the more vibration the more light; but the larger the body of ether to be set in vibration by any given source of vibration the more feeble the vibration will be, and consequently the less bright the light—*i.e.*, the less effect will it have upon the nerves of the eye.

Thus I construct a hollow pyramid 3 feet in height, and having a base of 9 square feet—*i.e.*, 3 feet in length and in breadth. I place the electric light at the apex, so that the rays of light fill the pyramid. If I put a screen across this at 1 foot from the light, it will measure just 1 foot each way—*i.e.*, 1 square foot. The space thus enclosed is filled with light—*i.e.*, the ether filling the interstices of the air is set in vibration with a force corresponding with the intensity of the light. This light falling upon the screen will be more or less refracted, reflected, and absorbed, according to the nature and surface of the screen. The reflected light will make the screen visible, and it may be seen if the eye be placed at any small opening in the side of the enclosure. If now the screen be drawn farther from the light, it will have to be enlarged to cover the base of the pyramid. At 2 feet from the light this base will be 2 feet each way, or 4 square feet. The light now fills the whole of the larger pyramid, there is a larger body of ether to be set in vibration, and the vibration is consequently less, just as any given motive power will move a large weight a less distance than a small one. The farther the screen be drawn back, the greater will be the body of ether to be set in vibration between the light and the screen.

It is not, however, merely because of its greater bulk of ether to be set in motion that the intensity of the light or vibration is diminished, but because of its increased lateral dimensions. Thus a certain area—say a square foot—of air is set in vibration, so as to produce a sound. As this vibration continues onwards its lateral area also increases, and the sound decreases; but if the vibration be confined, as in a tube, so that it moves only longitudinally, and not laterally, the sound may be conveyed with but little diminution for considerable distances. Thus, by using a speaking-tube, a whisper from a room at the top of a house may be made quite audible in the kitchen, or *vice versa*. This speaking-tube is nothing more than a pipe which allows the longitudinal extension of the vibration, but prevents any lateral spreading, and consequent decrease in intensity. This may be illustrated by noticing the passage of any liquid, such as water, through a narrow pipe that becomes gradually wider and wider. If it be poured rapidly in at the narrow end, it will preserve its

original velocity so long as the pipe remains unaltered in size; but as it increases, so will the velocity of the water diminish. Just so with the vibrations of light, heat, and sound. If they be confined laterally, they continue with but little diminution of intensity, the original impetus sufficing to preserve them almost unaltered. But if they be free to expand laterally (*i.e.*, to radiate), this original force is continually diminished by the force necessary to set into vibration the additional air or ether.

That it is not the increase of bulk, but of lateral dimension, that decreases the intensity of light or heat, may be shown by the apparatus just described, of a source of light or heat placed at the apex of a hollow pyramid, so as to set in vibration the contained ether. We have seen that the light or heat decreases as the base of the pyramid is removed farther from the apex, and becomes consequently larger. We have also seen that the area of this base increases with the square of the distance from the apex. At 2 feet it is four times the size it is at 1 foot, and at 3 feet nine times. But the amount of air contained in the pyramid becomes greater, not as the square, but as the cube, of the distance. Whatever be the amount of air when the base is 1 foot distant, it is not four but eight times as great when the distance is doubled; and not nine but twenty-seven times as great when it is trebled. If the base at 1 foot distance be 1 foot square, then the quantity of air in the pyramid is $\frac{1}{3}$ of a cubic foot; at 2 feet distance the area of the base will be 4 square feet, but the quantity of air contained will be $2\frac{2}{3}$ cubic feet, or $\frac{8}{3}$; at 3 feet distance the base will be 9 square feet, but the quantity of air enclosed will be 9 cubic feet, or $\frac{27}{3}$.

Thus, in fig. 159 the volume of air between the light and the first screen is only $\frac{1}{8}$ of the volume between the light and the second screen, estimating only the portion contained in the pyramids.

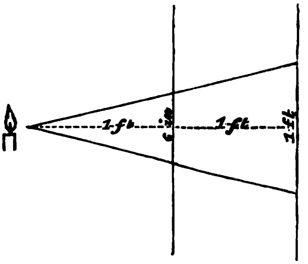


Fig. 159.

If the light or heat affecting the screen (or the base of the pyramid) depended upon the quantity of ether set in vibration, then the intensity of the light falling on it at 2 feet would be $\frac{1}{8}$ of that at 1 foot, and at 3 feet $\frac{1}{27}$; but we know by actual experiment that this is not the case.

If it depended upon the surface lit up or heated, the decrease would be to $\frac{1}{4}$ at 2 feet, and to $\frac{1}{9}$ at 3 feet, and experiment gives these as the actual ratios. Therefore it may fairly be assumed that light and heat do vary inversely as the surfaces upon which they *fall*. *The same* appears to be true of sound, though

the vibrations of air, which we call sound, seem to be of a grosser and stronger character than those vibrations of the more subtle medium which we call light and heat. This difference in nature makes the language used for one occasionally inappropriate to the other, but the differences are in the nature of the vibrating medium, and in the causes and effects of the vibrations, and not in the laws governing them.

It is often said that light and heat decrease inversely as the area upon which they fall, because being spread over a larger surface they are necessarily lessened in intensity in just that ratio; just as any given quantity of water would fill a broad vessel to a less height than a narrow one.

But the analogy is not complete, and it may be doubted whether the mere extension of the surface is the cause of the diminution of intensity either in the case of light or of heat. Any analogy, such as between water and light, is necessarily imperfect, because one is a tangible substance, and the other but a state or condition of a substance. It would be as reasonable to push to a logical extent any analogy between a liquid and a vibration, as to insist upon one between the body of one man and the temper or influence of another, or between the trunk of one tree and the shade cast by another.

By no means could one gallon of water be made to counterbalance another, so that both should cease to exist; but it is quite possible for two rays of light to produce darkness, by ceasing to exist as light. But though these two vibrations would each destroy the other, it would be the vibration, not the ether, that would cease to exist. Since, therefore, light can be destroyed, it follows that it is not simply because of the increased area that the intensity of the light is reduced in just the ratio of increase. If so, it would also follow that as the area was diminished the light would increase. Practically it does so, but not necessarily, as the increase may be prevented by the interference of another ray of light.

The real reason of the variation of light and heat inversely as the area of surface, is the greater lateral area of ether that has to be set in vibration by the original force. If a light be placed at the end of a long tube of small bore, having a bright inner surface, it will be seen by an eye placed at the other extremity with a brilliancy but little diminished by distance, for in this case radiation is prevented by the sides of the tube, and the vibration can extend only the lengthway of the tube. In this direction it is impelled by the light at the end, and as this is a constant force there is no loss or diminution.

If now I fix at the end of the tube a funnel (which is really a hollow pyramid), the light, after passing through the tube with but little diminution, will, as soon as it enters the funnel, begin to radiate, and will in the same ratio diminish in intensity. The action on the ether in the funnel, and the amount of light falling

upon a screen at its broad end, will be almost the same whether the light pass first through the tube, or the tube be removed and the light placed at the small end of the funnel.

We might reasonably expect that just as light decreases with radiation, so it would increase with condensation—*i.e.*, that if we can converge vibrations, the result will be an increase of intensity. We cannot do this by simply placing the light at the wide end of a funnel and noting the effect at the narrow end, because it is necessary to have a body of ether already in regular longitudinal vibration gradually converged. But by placing at the end of a tube a funnel reversed, we may obtain the necessary conditions. The vibrations continue along the tube and into the funnel. Some will pass directly through the narrow end on to the screen placed to receive them, and will illuminate it with the intensity due to them. Others will strike on the inner surface of the funnel and be reflected (and, if necessary, re-reflected) until they too pass through the narrow opening on to the screen, which will now be illuminated with increased intensity. Excepting the loss occasioned by these reflections, the whole of the light falling on the wider end of the funnel will be condensed on the smaller surface attainable by passing through the narrow end, and in this way may be illustrated the converse law of radiation. If the inside of the funnel be polished, most of the light will be reflected ; but if it be roughened and blackened, most of it will be absorbed.

So that, finally, we may say that given any amount of vibration (either light or heat), the intensity of the light or heat produced will depend, not on the surface receiving it, but on the amount of lateral dispersion. Practically, the two are the same, but in theory there is an important distinction. It must be continually kept in mind that Light, Heat, Sound, are not *matter* but *motion*.

But the amount of lateral dispersion depends upon the distance from the point at which the radiation commenced. If at the distance of 1 foot, 1 square yard be illuminated, then at a distance of 2 feet, the illuminated space will be 4 square yards; at 3 feet, 9 square yards — that is, *the area affected varies as the square of the distance.* This is **the law of inverse squares.**

Area affected,	1,	4,	9,	16,	25,	36,	49,	64,	81,	100,	&c.
Distance,	1,	2,	3,	4,	5,	6,	7,	8,	9,	10,	&c.
Intensity,	1,	$\frac{1}{4}$,	$\frac{1}{9}$,	$\frac{1}{16}$,	$\frac{1}{25}$,	$\frac{1}{36}$,	$\frac{1}{49}$,	$\frac{1}{64}$,	$\frac{1}{81}$,	$\frac{1}{100}$,	&c.

Whether the force be evident as heat, light, or sound, the law holds good. If I increase any given distance, the area affected is increased, but the intensity of effect diminished, and both increase and decrease are as the square of the distance. I can take any distance as unity. If I take 1 foot, then at 4 feet I get 16 feet ($= 4 \times 4$) of area affected, but a force diminished in intensity to $\frac{1}{16}$ ($= \frac{1}{4} \times \frac{1}{4}$). If I take this 4 feet distance, 16 feet area,

and $\frac{1}{16}$ of intensity, then at 8 feet I get 64 feet area (= 16 × 4), and an intensity of $\frac{1}{64}$ (= $\frac{1}{16} \times \frac{1}{4}$). If I take 3 feet as unity, then at twice that distance I get 36 feet area (= 9 × 4 = 36), and $\frac{1}{36}$ of intensity (= $\frac{1}{9} \times \frac{1}{4}$).

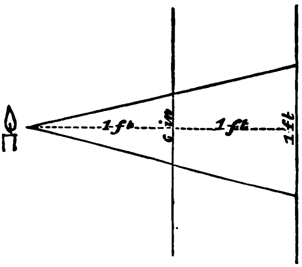


Fig. 160.

In fig. 160, 6 inches square (= 36 square inches), at 1 foot from the light, becomes 12 inches square (= 144 square inches) at 2 feet. At twice the distance the extent illuminated is increased fourfold. At three times the distance—*i.e.*, 3 feet, the illuminated area would be 18^2 = 324 square inches.

(3.) **Form of Radiation.**—It is usually said that radiation takes place in straight lines, the source of light or heat being the centre of radiation. But there are really no such lines. The vibration is communicated from the light to the ether all round it, and this light becomes the centre of a sphere of vibrating ether, which extends indefinitely far in every direction until some obstacle prevents its farther progress. As to how far from its source this vibration, whether of heat, light, or sound, be perceptible by our senses, depends upon the particular power of perception of each person. Probably no two people have exactly the same range of vision, hearing, or general perception, since probably no two eyes or ears are precisely equal in all respects of structure; and if two persons had eyes or ears exactly alike, there might still be a difference in the structure of the nerves or brain that would prevent the mental impressions received being exactly alike.

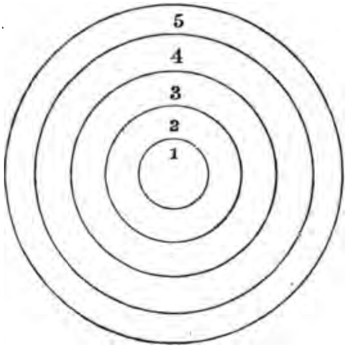


Fig. 161.

It will help very much the full comprehension of the nature of light, heat, sound, &c., and of the laws governing them, if it be clearly understood that from every source of either of these the vibration is in the form of a sphere, of which the source is the centre; and that this sphere extends indefinitely in every direction, until stopped by some substance which is impenetrable by the particular vibration. But even when thus, at any one point, brought to rest, the light, heat,

sound, &c., will, as it were, embrace the obstacle; and, if there be space, will pass behind it from either side. These spheres are shown as circles in fig. 161.

If there be no obstacle in the way of radiated light, heat, or sound, it continues for an indefinite distance, and probably exists long after it has become too much weakened by diffusion to be perceptible by human senses. It will be seen that radiation is precisely the same for heat, light, or sound, so far as the method and laws are concerned. But they differ materially in the direction, the amplitude, the velocity, and the number of the waves.

If 1 be the position of the source of light, heat, or sound, then 2, 3, 4, &c., will be the successive spheres of motion generated. It is generally said that these concentric spheres resemble the coats of an onion, and are all of equal thickness—*i. e.*, that the amplitude of each wave is constant. But I think a little consideration will show the probability of a continued though small diminution of amplitude in every successive wave.

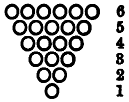


Fig. 162.

If I roll one marble against another, it moves it a certain distance. But if I roll it, with equal force, against two close together, it moves each a certain distance, but less than it moved the one. If now I place a group of marbles as in Fig. 162, and impel another marble against the single one forming the apex of the triangle, that delivers its force to the two marbles in row 2, half to each. From these the same force passes to the three in row 3, one-third to each, then to row 4, one-fourth to each, then to row 5, one-fifth to each, and so on, the total force applied to the whole number in each row being unaltered, but each successive atom being urged by diminished force.

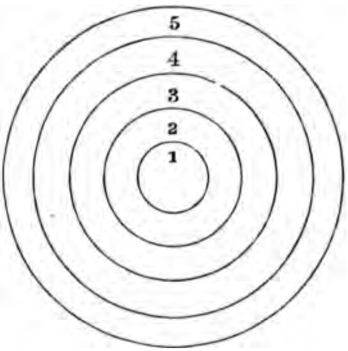


Fig. 163.

Now it is evident that the hollow sphere marked 4 contains a greater number of atoms than the hollow sphere marked 3, and this a greater number than 2. If the same force that makes wave 1 makes also waves 2, 3, 4, &c., then it is evident that, since it is divided amongst a continuously increasing number of atoms, it must have upon each a continuously-diminishing force. Therefore the distance it will move the atoms of each successive sphere will be less and less—*i. e.*, the amplitude of each successive wave will be less and less,

diminishing by very small amounts, but still surely diminishing, however slowly.

(4.) **Amount of Radiation.**—The amount of radiation depends on the *surface*, and not upon the *nature*, of the radiating body. In this respect it resembles reflection. A smooth, bright surface allows of the least radiation, and a rough dull one the most. Dish-covers, metal teapots, and such articles, all radiate heat, but the less in amount in proportion as they have smooth surfaces, and are kept brightly polished. If two covers be made of equal sizes and thicknesses, but one quite plain and the other engraved, it will be found that the plain surface radiates less than the other, the sharp edges and points of the engraved surface being so many centres of radiation—doors, in fact, for the escape of heat.

A good radiating surface is usually a bad reflecting one, and *vice versâ*, since the conditions of the two are opposed. Reflection requires smoothness, radiation is better from a rough surface. Reflection, however, is like radiation in proceeding from the surface only. But in this, while they have one point of resemblance, they differ, in that reflected light or heat falls on the surface reflecting it, while radiated light or heat usually comes from within, through the body from whose surface it radiates. A vessel containing hot water, a metal ball that has been heated, are examples of radiation of heat, while in the case of light it is not so easy to find an illustration of a radiating surface other than the source of light itself. A candle in a lantern may be taken, but the light itself is really the centre of radiation. The light passing through the glass is really refracted light, refraction being only a change in the direction of radiation.

A teapot filled with boiling water cools more or less rapidly when placed on the table; more rapidly if there be many points or other projections, less rapidly if it be smooth and well polished. If I varnish the teapot, it cools more quickly; so it does if I cover it with lampblack, whitelead, velvet, sealing-wax, flannel, or any rough or loose substance. If I substitute an earthenware or glass teapot for a metal one, I find the rate of cooling increased.

(5.) **Causes of Radiation.**—Radiation of heat is really the action of the heated body on the surrounding air, the heat passing off through the air in all directions. Radiation of sound is precisely the same, differing only in the number and size of the vibrations or waves. Radiation of light also is still the same. Assuming heat, light, and sound to be vibrations, then, whenever we have a body in vibration, it will give off in all directions the force derived from the vibratory state. I ring a bell, vibrations are given off to the surrounding air in the form of sound-waves; I *light a candle*, vibrations are given off in the form of light-waves; I *fill a tin* can with hot water, vibrations are given off in the form

of heat-waves. So that the only *cause* of radiation is the existence of motion amongst the molecules of some body, which motion is continually transferred to the surrounding air. This transfer *is* radiation. As the bell comes to rest, the sound-waves cease; as the candle dies out, the light-waves cease; as the hot water cools, the heat-waves cease. The motion at first existing in the bell, flame, and water is gradually spread out and diffused amongst all the bodies in the neighbourhood.

When a fire is first lighted in a cold room, but little warmth is felt from it, but the room continues warm for some time after the fire has gone out. The heat of the fire is still really in the room, radiating from the tables and chairs and other furniture. At first the coals are warm, the furniture cold; gradually the room becomes warm because the heat of the fire is transferred by radiation to every surrounding article, which then begins to give off heat in turn. So that every piece of furniture is as truly a source of heat as the fire itself, so long as it retains any heat.

(6.) **Result of Radiation.**—Radiation is simply the transfer of force, it may be as heat, as light, or as sound; it may be in some other form. The one result is the transference from one place to another of a certain amount of force or energy. I light a gas-stove and the room becomes warm, radiated light has become heat, but the energy producing the light is transferred to the furniture of the room, or its walls, and there reproduces that energy as heat. I ring a bell in the middle of a room, the sound is heard far beyond the room: the greater force of the sound-waves causes the radiation to pass through doors and walls, which sufficed to confine the heat and light, and the energy is diffused much more widely, but no less surely. The only certain result of radiation is the transference of force or energy. The form in which this energy may reappear is not necessarily the same as before the transfer.

(7.) **Causes affecting Radiation.**—We have seen (p. 272) that the radiation of heat from any vessel is determined in amount by the nature and contour of the surface. A silver tankard radiates less freely, when filled with boiling water, than an iron one. A leaden one would give off heat still more readily, especially if the surface were tarnished. A glass vessel cools very much more rapidly. Covered with paper, its power of radiation would be nearly a maximum; and if I desired to get rid of the contained heat by the most rapid radiation possible, a coating of whiting or lamp-black would accomplish this.

Silver	5
Iron	15
Lead	20
Oxide of lead	50
Glass	90
Paper	98
Whiting	100
Lampblack	100

If we were asked what property, common to all these, decreased regularly from silver to lamp-black, or increased regularly through the same series, probably we should say the capacity of being polished,

of having the particles arranged in a perfectly level manner, was greatest in the case of silver, and decreased through iron, lead, &c., to lampblack. But it is probably the compactness, and not the smoothness, that retards radiation.

The above list shows that iron radiates thrice as readily as silver, lead four times, glass eighteen times, and lampblack twenty times as readily.

(8.) **Nature of Radiation.**—The passage of heat through a solid we call *conduction*, through a liquid either *conduction* or *convection*, but through a gas or air *radiation*. We may say that radiation is *conduction through air*, or that *conduction* is *radiation through a solid*. If there be an ether whose vibrations alone are heat, then the communication of this vibration from particle to particle is *conduction* when the particles occupy the interstices of a solid, but *radiation* when they are diffused through a gas. If B be a pyramid of metal and A a vessel of water placed above it, then if a gas flame, or heated ball of iron, were placed at the point where A and B are in contact, the heat would be *conducted* downwards through B, *conveyed* upwards through A, and *radiated* right and left through the air at C and D.

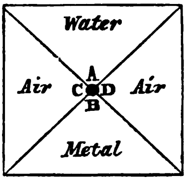


Fig. 164.

The name *radiation* suggests the idea that the transfer of force is *radial*, spreading laterally wider and wider as it travels outwards from its source; and practically it does so, but whether this is a necessity of radiation is at least doubtful.

O O O O O O O If a row of marbles be moved by a force acting on one, the whole force will be transferred from marble to marble, less only what is lost in friction, but it is impossible to imagine a force acting only on one row of air particles; we cannot conceive of one distinct row of aërial atoms as being acted on without any effect upon the particles right and left, above and below.

It is much more easy to imagine that each particle acts upon several others, say three or four at least, the force of the one being diffused amongst the others, each having but a share, and this share being the smaller as the number of particles acted upon increases. Therefore the more compact the particles, the more would there be to divide the force; and the less compact, the greater would be the force communicated to each, and the greater force with which each would act on the surrounding air.

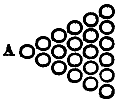


Fig. 165.

In the case of projections, or points, just the reverse would be the case; the force would proceed from the greater to the less number. In fig. 165 the force proceeding from left to right would

be subdivided, and for each particle reduced; but proceeding from right to left, would be condensed at the point A, which would move with more force accordingly. So that it is probable that it is upon the compactness of the particles composing the surface, and not upon the smoothness of the surface, that the degree of radiation depends. But since the smoothness is so much more easily observed than the compactness which it usually accompanies, it is natural that the smoothness, and not the compactness, should be taken as the cause.

If we assume the truth of the ether theory, then we may say that the more compact a surface the less room for the ether to occupy; and the more porous the surface, the more room for the ether particles. So that here, as in so many other points, either of two theories explains the facts, and is consistent with them. But whatever be the true theory, the fact is, that every body containing heat is constantly giving off this heat by radiation. This is, however, only a truism. A heated body is a body whose particles are in a state of vibration: to vibrate is to move; particles moving must come in contact with the air, or whatever else may be in close proximity to them; this contact must communicate force; this force is really what is evident as heat; when the force is transferred, the power of appearing as heat goes with it.

(9.) **Examples of Radiation.**—The light and heat of the sun are conveyed by radiation; so are the heat of a fire and the light of a candle. The formation of dew is another example. During the day, heat comes to the earth from the sun and is radiated again from the earth. This radiation continues after the reception of heat from the sun ceases—in fact, continues all night. If the night be cloudy, the clouds reflect back the heat again to the earth; but if it be cool and clear, the heat passes away into space, and the earth and the air near it become so cool that the water vapour contained in the air becomes condensed, and forms the water drops noticed on the leaves of trees, &c. So long as the air is kept in agitation by vibration (*i.e.*, heat), so long the water exists only as vapour, the invisible particles being scattered by the constant motion; but when the earth cools (*i.e.*, becomes still), these invisible particles of vapour congregate by mutual attraction, and become visible as water.

(10.) **Laws of Radiation.**—I feel more heat from a fire if I stand in front of it than if I stand at the side: the sun is hotter (*i.e.*, gives *us* more heat) when it shines directly down at noon than when its heat reaches us, at morning or evening, sideways. In the one case (the fire), the heat going to the side leaves the bars making but a small angle with them; in the other, the sun, the heat leaves its source at a right angle, but reaches, after sunset, at a small angle. In either case the heat communicated becomes smaller and smaller as the angle of departure or reception be-

comes smaller. From experiments upon this point is derived the

1st Law of Radiation.—*The amount of heat derived from radiation varies with the* cosine *of the angle, either of departure or reception.*

The greater the temperature of the heated body, the more heat is given off by the radiation. The more energetically the particles move, the more force do they communicate to the surrounding medium. From this we get the

2d Law of Radiation.—*The amount of heat radiated varies with the temperature of the heated body.*

The farther off I am from a fire, the less warmth I get in any given time; and the nearer I am, the more I get. This is an example of the law of inverse squares. From this we get the

3d Law of Radiation.—*The amount of heat received varies inversely with the square of the distance.*

SUMMARY.

(1.) Radiation is the giving off of force, either as heat, light, or sound. Page 265.

(2.) Radiation is governed by a law known as the law of inverse squares. Page 266.

(3.) The radiating waves of force are usually spherical in form. Page 270.

(4.) The amount of force radiated depends on the surface of the radiating body. The more compact are its atoms, the less force is radiated. Page 272.

(5.) The motion of the radiating body is the cause of radiation. Page 272.

(6.) The result of radiation is the transfer of force from the radiating to the absorbing body. Page 273.

(7.) The term radiation is usually confined to the transfer of force through gases, but conduction and convection may be considered as phases of radiation. Page 274.

(8.) Radiation, like all other actions of force, is governed by laws. Page 275.

ABSORPTION.

PENETRATION.

(1.) **Absorption.**—If I allow light to fall on a bright looking-glass it is almost entirely reflected. If I remove a portion of the quicksilver from the back of the glass, the light is almost entirely transmitted—*i.e.*, instead of being reflected it passes through the glass. If, now, I cover the mirror with a piece of thick black velvet, the light is neither reflected nor transmitted, is no longer perceptible on either side of the glass, but is, as it were, swallowed up by the velvet. It may be asked, "what becomes of it?" for it must be recollected that force is as indestructible as matter. Light may be destroyed, or rather the impression of light may no longer be produced, but the vibration which produced it must produce some other effect instead, or assume some other form.

We know that heat and motion are two phases of one and the same force; that motion prevented assumes the form of heat. It is very probable also that heat and light are but two phases of the same force, and that light absorbed or destroyed assumes the form of heat. It must be borne in mind, however, that while heat and motion may be changed and rechanged into each other, light once absorbed seems to be but very seldom capable of reappearing as light.

(2.) **Colour from Absorption.**—Absorption is a kind of refraction; it breaks up the intimate union existing between the several coloured rays of light, and so produces colour. Thus light falling on a piece of red glass becomes red thereby. That is, the glass absorbs all the light excepting the red ray, and that reaches our eye, giving us the form of the glass and associating with it the impression of red. This is the only reason we have for calling the glass red. The same is the case with other coloured objects. They derive their peculiar colours from the absorption of all the other colours. The red glass reflects light as well as transmits it, and appears red on either side, but the light reflected from the first surface is white light. The colouring matter of the

glass, the constituent which absorbs the other rays of light, reflects some of the light that reaches it, and this, not the first reflection, it is that makes the glass look red from above, while the transmitted light passing through the glass is partly absorbed, and the remainder wholly consists of the red rays, which make the glass look red from below.

It is to this same absorption and reflection combined that we owe the marvellous shades of colour which we find in flowers and fruit. The light falling on them is reflected after partly penetrating their substance, and being partly absorbed both in entering and returning, gives the endless varieties of colour and shade which we see, and which probably could not be produced in any way by mere surface reflection.

All that we understand by colour depends upon this absorption of some of the rays of light. Thus paper is white when it reflects all the rays of light falling on it. A rose is white if it reflect all the light ; or red if it absorb all but the red rays. The colour of drapery, carpets, leaves of trees, and of everything that we call coloured, depends upon the absorption of all the light excepting the rays that have the particular colour. When we say that any thing is red, green, blue, &c., we ought rather to say that it absorbs all light falling on it, excepting only the particular ray or combination of rays that give the impression of red, green, or blue.

(3.) **Total Absorption.**—When we say that anything is black, we mean really that it absorbs all the light and reflects none. Probably nothing is so completely black as to do this, but many things absorb very nearly all the light they receive. Roughness seems to be very favourable to absorption, or, to speak more accurately, very unfavourable to reflection. Almost every substance reflects some of the light falling on it; but if the surface be rough, some of these reflected rays cross each other, and others, falling again upon the surface (owing to its irregular surface), are again partly absorbed; and in this way, by interference and continued absorption, most of the light is destroyed as light, and but little is reflected.

If I place myself in front of a cannon of small bore, and look into it, my face being a few inches from the mouth, I see nothing whatever. No light can enter, and consequently none can be reflected to my eye; so that it is literally true to say that though my eyes are wide open, I cannot see anything. The tube is before me, and appears perfectly black. This is not because of the absorption of light, but because there is no light to be either absorbed or reflected. This shows also that for any object to be seen it is not sufficient for it to be placed before the eye. If a rough black hat or coat be hung up in a room not well lighted, it may, with but very little exaggeration, be said that it is really invisible. I know exactly where it

is, and might well be excused if I declared that I had in my mind a very accurate idea of its size, shape, and general appearance, derived from the impression obtained by means of my eyes. All this is quite true, and yet it is doubtful if I can with accuracy be said to see the coat. Supposing it to be hung against a white wall, that portion of the wall behind it is invisible to me, but the shape of this portion is accurately defined by the outline of the coat. Since this piece of wall is the shape of the coat, I get from this an idea of a coat; and so with anything else that is completely black, I get an idea of its form and character, not so much from the light reflected from it, as from the fact that I cannot see what is behind it. Thus if I place a circle, or diamond, or cross of black paper on a white sheet, I get my notion of the form of the circle, diamond, or cross, not so much by seeing it, as by *not seeing* the white sheet behind it.

(4.) **Absorption of Light.**—A black curtain absorbs light, but does not become luminous. It also absorbs heat, and does become heated. Is it that absorption of light differs from absorption of heat—that one is destructive and the other collective? A body that absorbs heat is thereby heated as a sponge that absorbs water becomes wet. In this case absorption means merely the arrest and collection of the heat. What becomes of the light absorbed—*i.e.*, arrested and not collected?

The explanation is simple. Light absorbed ceases to be light and becomes heat. A little consideration will make this easy to comprehend. Heat falls on a polished steel mirror, and is reflected, just as light would be. It falls upon a rough blackened surface, and is not reflected, but absorbed. The steel surface that reflected the heat was not itself warmed by the heat so reflected. But the rough black surface that did not reflect the heat is itself warmed by the heat not reflected, but collected. The cable tank of the Great Eastern fell 8° F. when the outside of the ship was fresh whitewashed on her voyage to Bombay in the early part of this year, 1870.

So light falling upon the polished steel surface is reflected, and the steel reflecting surface is not affected by it. Light falls upon the rough blackened surface and is not reflected, the surface being heated by the absorption. But it may be asked if the absorbed heat warmed the absorbing surface, why does not the absorbed light make it bright? Because light is only light when it enters the eye. Light that does not do this, that does not act on the optic nerve, ceases to be light. Absorbed light cannot do this, for if it could it would not be absorbed. It is the very essence of absorption that it is the reverse of reflection, or of any form of radiation.

The phrase "absorption of light" may therefore be said to be equivalent to "conversion of light into heat," and might we not be tempted to say that light was simply visible heat?

(5.) **Amount of Absorption.**—This, as in the case of radiation, depends upon the surface rather than upon the nature of the body upon which the vibration falls. This is equally true whether the vibration be that of sound, heat, or light. It is simply that *force* of any kind falling upon any body is reflected or refracted according to the ordinary laws of mechanics. If the surface be bright and smooth, almost the whole of the force will be reflected, not so much because of the smoothness as because of the compactness which renders smoothness possible. If the surface be rough, these reflections are in various directions (being, in fact, what is technically termed "scattered"), and so partly intersect and neutralise each other; if the substance be of loose texture, then the force passes inwards from particle to particle instead of being reflected.

A cannon-ball striking against solid masonry is reflected (unless the masonry be too weak to resist the force), but the same ball striking an earthwork is buried in it. The one is an example of reflection, the other of absorption. In the one case, the greater part of the force is spent in throwing the ball back; in the other, it is almost entirely spent in compressing the comparatively loose earth. In the one case the particles (of stone) are compact, and no particle can move far without coming into contact with the next; in the other, the particles (of earth) are separated by far greater intervals, and the motion communicated to each particle is abstracted from that of the ball. It is not that the mound of earth *absorbs* the ball, but that the ball has more power to penetrate the earthwork than the earthwork has cohesion to resist its passage. In the case of the stone wall the reverse is the case; the power of cohesion is greater than the power of penetration.

So that while *reflection* is an appropriate term where the reflecting body controls the motion of the impinging body, it is not so clear that *absorption* is so suitable where the absorbed body exerts the controlling force. One might be tempted to suggest **Penetration** as a better term, if it were not that such a step would be certainly presumptuous, and probably confusing.

(6.) **Causes affecting the amount of Absorption.**—Retaining therefore the term *absorption*, we have to consider what circumstances control the amount of force absorbed. A moment's consideration will show, that of any given force falling upon a body, that part which is not reflected will be absorbed, and that part which is not absorbed will be reflected; in fact, that the whole force is divisible into two parts—one reflected, one absorbed. So that

$$F = R + A,$$

where F is the whole force, R the reflected portion, and A the absorbed portion. Therefore also,

$$R = F - A \qquad \text{and} \qquad A = F - R,$$

from which the amount absorbed depends upon the amount reflected. Therefore whatever favours reflection is unfavourable to absorption, and *vice versa*. Absorbed force is often transmitted.

(7.) **Results of Absorption.**—Light falling upon a mirror is reflected, the result being that the mirror is not so much affected by the force as it would be if the force had been absorbed. Light falling upon thick black velvet is absorbed—the light ceases to exist as light; therefore we may reasonably ask, What becomes of it? The curtain is more affected by a force it is said to absorb than by one which it reflects. What is the result of this absorption upon the curtain? It is not illuminated, but it is set in motion. This motion is not necessarily a waving to and fro of the curtain as a whole, but rather a tremulous motion of its particles—a vibration of each as the light falling on it is reflected, re-reflected, and destroyed as light, owing to the roughness of the surface.

This vibration is evident to the sense of touch, for the curtain is felt to he *heated* by the absorbed light. One result of absorption of light is, therefore, heat.

Heat falling on a mirror is in like manner reflected, and falling on a substance having a loose porous nature is absorbed. Absorbed light becomes heat. What does absorbed heat become? It does not necessarily cease to be heat. When light ceases to be light, and becomes heat, it does no more than pass beyond the limits within which it is perceptible by our eyes. There is no sudden change in the vibration at the time of its ceasing to be light. If the vibration had a conscious existence, it could not tell at what particular instant it passed the limits between light and heat. Just as a bird passes a window, just as a star passes the field of a telescope, just as a railway train passes into and out of sight, so may a certain vibration pass into or out of our field of vision. The change is one for us, and for us only; it takes place only in our sensation, and is altogether a matter of consciousness on our part.

Imagine a man shut up in a large room with one window through which light came to him, but which he could not approach. Imagine people throwing stones about in all directions, up and down, right and left. Only those that passed across the window would be seen by the prisoner. He would know exactly when and where he saw one of the stones, but the men throwing them would not know which he saw, still less the exact times at which each became visible to him, and ceased to be so. Just so by our sense of sight are we conscious only of those vibrations that act upon the eye, and even then only of those between certain limits of rapidity.

Absorbed light, we see, is heat; absorbed heat is also heat. But these two may be grouped together by saying that the absorption of motion is heat—*i.e.*, vibration. This simply amounts to saying that absorbed motion is retained, not transmitted or reflected. A

velvet curtain receives a certain amount of vibration either as heat or light, and it absorbs—*i.e.*, retains it. It is not sent through, or it would be transmission ; it is not returned, or it would be reflection. The curtain is not able to reflect the force ; the force is not able to move the curtain as a whole ; but it is able to set in motion the particles of the curtain amongst themselves. Just as, when a cannon-ball is absorbed by an earthwork too weak to reflect it and too thick to be penetrated, the force is spent in moving the particles of earth amongst themselves. This motion of the particles, without the motion of the curtain as a whole, *is* heat. So that absorption really means that a force too weak for penetration and too strong for reflection is spent in vibration of the particles of the body into which it penetrates.

(8.) **Examples of Absorption.**—In the spring of this year, the Great Eastern, when conveying the Indian Telegraph to Bombay, had a fresh coat of whitewash before entering the harbour. The immediate result of this was a fall of 8° in the temperature of the tank containing the cable. The sun's rays falling on the hull had been absorbed more by the dirty than by the clean surface, and this absorption became in time so great as to be transmission. Another example is the difference between light and dark coloured clothing. A dark coat is warmer than a white one of the same material, but not *because* it is dark. Its darkness and its warmth are two consequences of the same cause. The heat and light falling on it are absorbed ; therefore it is both warm and dark. A light coat reflects, more or less, the heat and light ; therefore it is both light and cool. The formation of colour, generally speaking, is an example of absorption. A ray of light falls on a flower, and is partially absorbed, the part reflected giving to our eye the sense of colour. But we must be on our guard against the possible error of considering white light as a reality compounded of various coloured lights. I have already spoken of this on page 118.

Can *sound* be absorbed ? If so, what becomes of it ? An omnibus makes more noise on an ordinary road than on a tramway, and can be drawn with more ease on the tramway than on the road. Here the noise is as much the result of force applied as the motion. Part of the force moves the omnibus, part produces sound ; motion is transferred from the horse to the vehicle, from the vehicle to the ground, from the ground to the air, from the air to the ear. But if there be no ear to receive the sound there is none. What becomes of it ? Clearly it is absorbed, just as heat or light would be under parallel circumstances.

While a carriage passes my window I cover my ears, and consequently do not hear it. The vibrations that, falling on my ear, would have been sound, now fall on my hands and are partially reflected, but chiefly absorbed. Through the open door of my room I hear a piano being played in the next room. I shut the

door and can scarcely hear it. The sound falling on the door is partly reflected, partly absorbed, and partly transmitted. That is, a sound-wave falling on the door does three things: (1) Sends back a smaller wave, *reflection:* (2) sets up a smaller wave on this side, which is audible to me, *transmission:* (3) sets in motion, amongst themselves, the particles of the door, *absorption.*

(9.) **Nature of Absorption.**—A sponge put in water absorbs some of it, and the water so absorbed will remain in the sponge, and require some force to recover it. A piece of leather or of bread will in like manner absorb and retain some of any water into which it may be placed. If I put the sponge, or leather, or bread, under the tap of a cistern, and turn the water on, some of it will be reflected, some absorbed, some transmitted. That is, some will rebound from the surface, some pass through, some will remain within the interstices of the sponge or leather.

Just so force is reflected, transmitted, and absorbed, by almost every substance in nature. Just as the water absorbed can be recovered, so can the absorbed force. Just as the water gradually disappears, leaving the sponge dry, so will the force be gradually diffused.

In football it often happens that the ball is for a time almost motionless under the influence of a number of conflicting forces, moving only short distances from boy to boy. Just so absorbed force consists in the motion to and fro of the particles of the absorbing body. But this absorbed force is given off little by little. As the motion of the particles amongst themselves reaches one of the outer particles, it is given off to the surrounding air.

So that absorbed force is no more than the parallel to *latent heat* (p. 86). We might call latent heat absorbed heat, or might call absorbed force latent force. The term absorbed force means a force that is not appreciable to our senses, and has no effect upon anything but the particles of the absorbing body.

(10.) **Absorption by gases.**—Heat and light pass through air with but very little loss—*i.e.*, the air does not absorb any very perceptible portion of any heat or light passing through it. The same is true of hydrogen, oxygen, and nitrogen. This led to the idea that gases were perfectly diathermanous. But chlorine, hydrochloric, and carbonic acids, and especially ammonia, are found to absorb, by comparison with air, considerable quantities of heat. Thus, considering ammonia to absorb any given quantity of heat in any given time, an equal quantity of hydrochloric acid will absorb, in the same time, only $\frac{1}{20}$ as much, and an equal quantity of carbonic acid only about $\frac{1}{12}$. Chlorine would absorb about $\frac{1}{30}$, while air, oxygen, nitrogen, and hydrogen, would each absorb less than $\frac{1}{1000}$ as much as the ammonia.

The *method of estimating* the amount of absorption is a very

delicate one, requiring great care. It consists, essentially, of a tube full of the given gas, through which a given amount of heat is allowed to pass. The effect of the transmitted heat upon the thermopile at the end is taken as a measurement.

SUMMARY.

(1.) Light or heat which falls upon a body and is not reflected is said to be *absorbed*. Page 277.

(2.) Colour is frequently due to light being reflected after being *partially* absorbed. Page 277.

(3.) Black objects are really invisible, owing to the *total* absorption of the light falling on them. Page 278.

(4.) Absorbed light frequently becomes heat. Page 279.

(5.) The amount of absorption depends upon the *compactness* of the absorbing body. Page 280.

(6.) Whatever increases reflection decreases absorption, and *vice versâ*. Page 280.

(7.) Absorbed light becomes heat: absorbed heat remains heat. Page 281.

(8.) *Absorption* is parallel to *latency*. Page 283.

(9.) Solids, liquids, and gases, all absorb more or less of any light or heat falling on them, but some gases but a very small amount. Page 283.

REFLECTION.

(1.) **Introduction.**—In order to fully understand how light, heat, sound, &c., can be reflected, we must grasp firmly the idea of what is meant by reflection. To *de-flect* is to bend away, to turn anything out of its original direction; to *re-flect* is to do this also, but to do it so that the thing turned out of its course is sent more or less back again towards its starting-place.

A ball thrown against a wall comes back again; the wall prevents its passage farther in its first direction, but the unspent force urges the ball on in the only direction it can move, which is from the wall more or less towards the starting-place. Force cannot be destroyed any more than matter, though it may be changed in its character. A croquet-ball striking against the hoop does not come to rest, for the same force that would have sent it through the hoop now drives it in another direction.

So a ray of light, or of sound, or of heat, falling upon any substance that it cannot penetrate, is bent on one side—*i.e.*, reflected. This reflection is just as real as that of a ball from a wall, though there is the great difference that with the ball there is a transfer of matter, the ball changing its place; while in the case of heat, sound, or light, it is motion, not matter, that is transferred. This may be illustrated thus: Until quite recently, bells in houses have been rung by means of wires and bell-pulls. I want to ring such a bell, and I pull a cord; this pulls a wire, the other end of which is fastened to the bell, which is moved on one side by my pull. A spring pulls the wire and bell-pull back to their original position, and the bell, being suspended loosely by means of a bent spring, is set in vibration. Here the result is effected by means of a transfer of matter to and fro; the wire is moved bodily first in one direction and then back again.

If now, instead of this method, I use the modern one of connecting the bell and my hand by means of an electric wire, I ring the bell, not by moving the wire lengthways as before, but by setting *in vibration* either the wire itself or some subtle

medium filling its interstices—which, it is not clearly known yet. The wire itself remains stationary, excepting, it may be, the slight tremor of each particle. In the one case I cause a transfer of matter—*i. e.*, I move the wire bodily; in the other, only a transfer of motion—*i. e.*, the wire remains stationary, but a tremor runs along it, each part being set in consecutive vibration.

The fact to be grasped now is that this tremor, this agitation of the consecutive particles of a body (or of some ether between them), can be conveyed, bent round, turned to and fro, sent hither and thither, just as really as an actual substance can be moved from place to place—*i. e.*, *motion* can be transferred in exactly the same way, and subject to precisely the same laws, as *matter*.

This transfer of motion may be well illustrated by transferring heat, light, sound, from one place to another. This may be done by using reflectors—*i. e.*, substances which do not transmit or absorb much of the vibration falling on them, and which consequently reflect the greater part of it.

(2.) **Parabolic Reflection.**—I take two parabolic reflectors, and place them opposite each other at a distance of some yards. The reflectors are of metal, silvered inside and brightly polished, that being the best substance for reflecting purposes. Their form is parabolic, because this form has the property of reflecting in parallel straight lines, which enables me to reflect light, &c., to any greater or less distance without convergence or divergence.

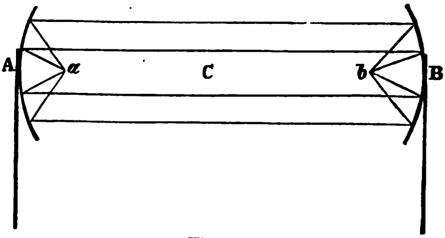


Fig. 166.

Having arranged my reflectors so that they are exactly opposite each other, I place in the focus of one any source of light, heat, or sound. I may put my reflectors on two chairs leaning against the backs, one at either end of the room (or on the floor), and place a spirit-lamp on one chair in the focus of the reflector. Where this point is may be easily ascertained by moving the hand about in front of the reflector, and noticing where it receives most light. This point is the focus. I find the focus of the second reflector in the same way. Fig. 166 shows the reflectors A and B with foci *a* and *b*.

I put a spirit-lamp or a candle in one focus. The light and

heat fall on the reflector, and are reflected in straight and parallel lines. These are received on the surface of the second reflector, which is placed so as to intercept them, and are converged to the focus. The image of the lamp will be seen in a small mirror placed at the focus, and a delicate thermometer placed there will rise from the heat falling on it. Removing the lamp, I place a watch in its place, and find the sound of its ticking to be carried to the focus of the second reflector just as the light and heat were before.

From these simple experiments it is evident that the vibrations which we call light, heat, and sound are capable of being moved from place to place, and diverted and reflected at pleasure. The same may be shown in a much rougher manner by means of any reflecting substance. A candle-end and a polished saucepan-lid will illustrate the reflection of light and heat in many ways.

(3.) **Instances of Reflection.**—The practical illustrations of the reflection of light and heat are innumerable. A light near a dark wall is half wasted through the absorption of light by the wall; if a mirror be placed between the light and the wall, the whole of the light is thrown into the room, partly by radiation, partly by reflection. A bedroom candle placed before the looking-glass on the dressing-table gives much more light in the room than when placed beside it. On the Underground Railway in London, light is carried down from the street by being reflected from a series of glazed porcelain surfaces, just as a stone thrown against the side of a well would rebound from side to side until it reached the bottom.

If a brightly-polished coffee-pot or dish-cover be placed beside a dirty one, the same amount of light will fall on one as on the other, but one will give us a reflected image, the other will not. The light falling on one will be regularly reflected, that falling on the other will be partly absorbed by the dirt, the remainder being reflected irregularly—*i. e.*, regularly so far as obedience to the law of reflection is concerned, but irregularly in *direction*, because the surface is not smooth. Light thus diffused by irregular reflection is sometimes called *scattered light*, and it is this light that enables us to see non-luminous objects.

I enter a shop, one end of which is entirely covered by a mirror. Every object in the shop is apparently doubled, and I have the impression of a shop twice the actual size. The mirror itself is invisible to me if it be a good one, and all I see, when looking at it, is the reflected light falling on it from the various objects before it. All the light so falling on it is either reflected regularly or transmitted. Well-cleaned windows are usually invisible from the same reason, all the light being transmitted or reflected. But if the mirror be a bad one, if it have blemishes or irregularities on its surfaces, these produce irregular reflection or scattering of the light, and from this light the mirror itself becomes visible.

Reading a book by a window through which the sun was brightly shining, I once noticed two small and bright circlets of light moving about on the page nearest the window, which was somewhat darkened by shade. I was puzzled for a time to account for these, until I found them to be reflections from two diamonds in a finger-ring. These reflected the sunlight so completely that the specks of light were as bright as if the light had fallen directly on the page, and were no larger than the reflecting surface.

(4.) **Formation of Images by Reflection.**—Regularly reflected light conveys the image of the source of light, so that if all objects were perfect reflectors none would be visible but those that are self-luminous. If the moon were a mirror, we should see, not the moon, but a reflection of the sun. But the light is not all regularly reflected from the moon, because its surface is not smooth, and so the light falling on it conveys the image of the moon and not of the sun, since the extent and arrangement of the reflected vibrations are determined by the size and shape of the moon and not by the sun.

Light from a candle or gas-light falling directly on a mirror conveys the image of the candle or gas-light. But if it fall first on a table or chair and then on the mirror, it conveys an image of the table or chair, because it is only partly reflected, and the extent and arrangement of the reflected vibrations are determined by the size and shape of the reflecting object, the other part of the light being absorbed or scattered. By the scattered light the table or chair itself is rendered visible.

If now I replace the mirror by a picture, the light, either from a gas-light or a table, or from any other object, will no longer convey any image of the light, table, &c., but will be rearranged by the picture, and will convey the image only of that. But if it be framed and glazed, there will be, in addition to this image, a slight reflection of other objects from the glass acting as a mirror.

From a metal reflector there is but one image conveyed, from a glass one two images are reflected; that from the second surface being usually the greater and clearer. Bringing a metallic surface in close contact with this second surface, I increase this reflection by substituting the reflection from a good reflector, such as a metal, for that from a bad one, such as air. This is what is really done in making looking-glasses. The light passes through the glass, and is reflected from the silver surface behind very much more clearly than from the front surface of the glass. In any shop window I can get a reflected image of my face, but from one having any article of metal, or any other good reflector behind it, I get a better image, because of the greater reflection. Or if there be a good absorber of light, such as a black hat or coat, I get also a better image, because of the absorption of light not directly reflected, and consequent greater clearness of reflection.

Light is not reflected from any object as a *whole*, but from each point of it. The ray of light from each point follows the law of reflection quite independently of all the others. So that if the object be placed in the focus of a parabolic reflector, it will be reproduced as an image at the focus of another by the regular reflection of the rays of light. They will travel side by side reproducing the figure when brought to a focus. The number of rays of light in a given space depends upon the size of the molecules of the body whose vibrations produce light.

(5.) **Practical utility of Reflection.**—In measurement of minute changes of position, the reflection of light is of exceeding value, as giving an accuracy very much beyond that of ordinary means of measurement. Thus, I want to measure a very small angle, such as that of a crystal. One way would be to place the crystal between the legs of carefully-made compasses, and to measure the angular distance on a circular arc. But by using the reflection of light as a means of measurement I get a more delicate and accurate measurement. The least projection or roughness on the compasses or the crystal would affect the accuracy of the result; but light is reflected by the whole face of the crystal, and any slight projection or foreign substance would be detected by this, instead of being a source of error.

Placing the crystal so that light falling from some given point on it is reflected, and noting the exact point to which the reflected ray proceeds, I turn it round until the same light falling on the second face of it is reflected to the same point. The distance through which I have turned the crystal, measured on a circular arc, gives the exact angular measurement.

In measuring the expansion of a solid by heat by the use of a pyrometer, the reflection of light gives a means of delicate measurement in the same way. In the pyrometer a solid is heated, and the amount of its expansion lineally is the test of the temperature to which it is exposed. The use of the thermometer is impossible, because mercury vaporises at very high temperatures, for the measurement of which the pyrometer is therefore used; but the expanding substance being necessarily a solid, the expansion is but little as compared with that of mercury in the thermometer. It is necessary, therefore, either to magnify this expansion, or to use exceedingly delicate means of measuring it. The first has usually been done by means of a series of levers of unequal lengths, so that the expansion has been multiplied; but this evidently opens the door to numerous sources of inaccuracy, even when the greatest care is taken. But by using the reflection of light as the means of indicating the extent of expansion, we can measure it at once. The substance to be heated is in contact with one end of an arm, the other end of which is fixed. The expansion of the heated substance necessarily turns this rod round its fixed end as a centre, though but a very small space. The upper

end of the rod is a mirror upon which falls a ray of light from a fixed point. As the rod moves, so does the mirror, and so does the reflected ray of light; and its change of direction marks the angular movement of the rod, and from this the movement of its free end, and consequently the expansion of the heated substance, may be calculated.

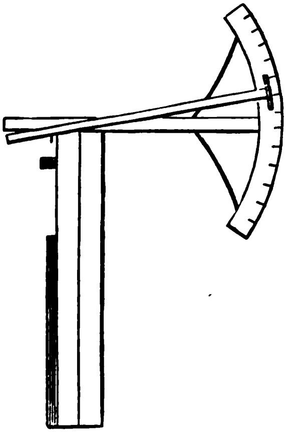


Fig. 167.

Fig. 167 shows an ordinary pyrometer. In the arrangement for measurement by reflection the scale is replaced by a mirror on the index, and a light is placed so as to fall on this mirror and be reflected to a screen, on which the scale is placed. The amount shown by the scale must be divided by two, because the light moves through twice as great an angle as the mirror.

(6.) **Reflection of Heat and Sound.**—I have described somewhat fully the reflection of light, because it is so much more readily observed than the reflection of heat, and much more easily produced than that of sound, but both heat and sound are reflected according to precisely the same laws. We are sensible of heat only by our sense of touch, and this is a much grosser and less trustworthy sense than sight. Of light we are sensible by means of our eyes, and only so; while we have no special organ of feeling, by means of which alone we are personally sensible of heat. To test the presence of heat, and to measure its amount, we are therefore obliged to depend on apparatus. But when we do this, we find that the reflection of heat is as real as that of light. One of the great moral results of physical science is this learning that natural phenomena are far wider and more universal than our knowledge of them; that our senses give us only the power of perceiving a little, but a very little, of the more striking and demonstrative portion of what is in operation around us; that we must not try to measure the universe by our measure, nor to limit it by our comprehension of it.

If I use the two parabolic reflectors, of which I have already spoken, for observations on the reflection of heat, I must call in the help of apparatus, since the heat-rays are not visible. The *source* of heat, to be placed in one focus, may be a gas-light, a *candle*, a spirit-lamp, or may be a heated ball of metal, a tin can-

ister of water, or any other substance radiating heat. Light is quite unnecessary. For the measurement of the heat so reflected, one of the most useful instruments is a *differential thermometer*, which is a glass tube bent so as to form three sides of a square, and terminating in two hollow globes. This is usually mounted on a wooden foot, so that it looks something like a very large and wide tuning-fork. The glass tube is partially filled with a liquid, coloured so as to be more conspicuous. The remaining space, consisting of the two spheres and the parts of the tube nearest to them, contains only air, but the whole is perfectly closed so as to completely exclude the external air. The instrument, therefore, always contains exactly the same quantity of water and air, the water being practically incompressible, but the air readily so. If one of the bulbs of glass be heated, the air will at once expand by reason of its increased temperature. But to do this the air in the other bulb must be compressed to allow of the water, which is driven down one side (by the expansion of the air) to rise in the other.

Fig. 168 shows a differential thermometer on a small wooden stand, and having two wooden registers, one below each bulb. The water-mark falls in one as it rises in the other. One is marked from the top downwards, the other from the bottom upwards.

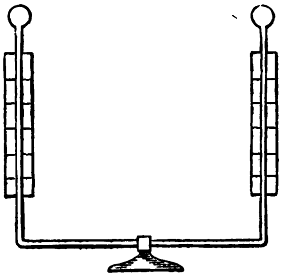


Fig. 168.

In this way the coloured water moves to and fro, giving ready and accurate evidence of the presence of heat. So delicate is this instrument, that the warmth of the hand is quite sufficient to cause a rapid expansion of the air, and consequent depression of the water. Such a measure of heat placed in the second focus of the reflectors will give evidence of the transfer of heat, if any take place.

Placing in one focus some source of heat, and in the other one bulb of the differential thermometer, I find at once that the air in the bulb expands, as is shown by the movement of the water. The other bulb will be unaffected by the heat, because it will be out of the focus, to which all the heat is reflected. It might be thought at first that the heat came direct from one focus to the other, but if so, the water would move in the contrary direction to that which it does take; and, moreover, that this is not the case may be shown by interposing a screen, first between the source of heat and the thermometer, when it has no effect; and, secondly, between the thermometer and the reflector, when the supply of heat will be at once cut off, and the thermometer will slowly recover its equilibrium. This shows conclusively that

the heat travels from its source to the first reflector, thence to the second, and thence to the thermometer.

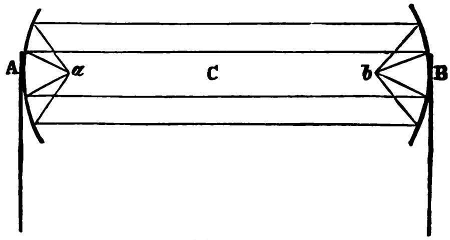


Fig. 169.

If instead of the thermometer I place gunpowder or phosphorus in the focus of the second reflector, the reflected heat will (if the supply be sufficient) explode the gunpowder or inflame the phosphorus. But I may also place a substance that is colder than the thermometer, such as a freezing mixture, ball of snow, &c. In this the thermometer will be affected conversely, and the bulb near the reflector will be colder than the other. This used to be accounted for by saying that the snow had radiated *cold* just as the sun radiates *heat*. But a more rational explanation is, that the snow being colder than the thermometer, the previous condition of things is reversed, and the thermometer becomes by comparison the heated body, and radiates heat to the snow, which melts gradually.

(7.) **Double Reflection.**—I place a candle before a mirror, and I see the reflection of it in the glass. I place another mirror on the opposite side of the candle, and I now see many images in each glass. Firstly, there is the direct image from the candle in each mirror, and each of these is again reflected in the other mirror, and each of these re-reflected images is a third time reflected, and so on, multiplying the number of images until they are too distant to be perceptible. But why do not these images coincide? Why should the result be more than to intensify the light in the mirrors? If the eye could be where the candle is, that would be the only result. There would be but two images, each much brighter than if but one mirror be used. But if the eye be anywhere else, it receives the impression of two series of images, in lines at right angles to the surface of the mirrors. And for this reason: It is explained (page 296) that any object seen in a mirror appears to be as far behind the mirror as it really is in front of it. This will explain why I see a series of images when I use two mirrors. Thus I place a candle between two looking-glasses, *at a foot* distance from each. In one mirror I get an image A *reflected*, and in the other an image B. Each of these ap-

pears to be one foot behind the mirror. But when I get a reflection of each of these, each reflected image appears to be more than

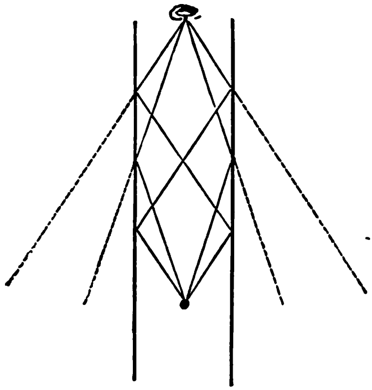


Fig. 170.

a foot behind, because the image of which I see the reflection is more than a foot before it. In the first case I see the reflection of an object 1 foot distant, and in the second the reflection of an image in the other mirror which is itself 2 feet distant. In this way each successive image appears to be more and more distant. Fig. 170 shows the lines of reflection.

Instead of keeping the mirrors parallel, I place them at an angle of 60°. The images are no longer in a straight line, but curved. They follow the same law of formation as before, but the different arrangement of the mirrors produces a different arrangement of the images. The lines of reflection are shown in fig. 171, only the curve should be a circle passing through the object, and having as a centre the meeting-point of the mirrors.

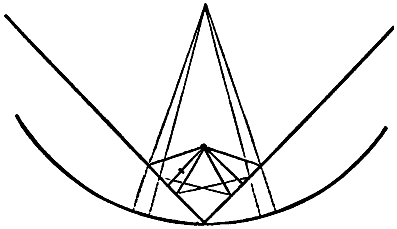


Fig. 171.

This is the arrangement of the kaleidoscope, in which, by placing *two small mirrors* at an angle of 60°, each point of a

small coloured figure is seen as a circle, and the whole pattern is repeated six times, so as to form a hexagon. If the mirrors were at an angle of 45°, the figure would be an octagon ; if at 30°, the figure would be twelve-sided. 360° divided by 60° gives 6, divided by 45° gives 8, divided by 30° gives 12. This supplies the rule for finding what figure any given arrangement of the mirror will give, and also how to arrange them to produce any given figure, provided it be a possible one.

(8.) **Reflection from Curved Surfaces.**—Light falling upon a curved reflecting surface is reflected according to the same law as when it falls upon a plane surface. Each ray is reflected as much on one side of the perpendicular as it falls on the other, however small may be the surface having the same perpendicular. If the surface be regularly curved, the rays of light falling on it are reflected symmetrically ; but if light fall on a rough surface the reflections are very irregular in fact (though each ray follows the law of reflection), and interfere so much with each other that the light is partly destroyed, and no result is perceptible except that *scattered* light which makes the surface visible.

So that we might group reflecting surfaces thus :—

(1.) Perfectly smooth plane surfaces : *i.e., mirrors from which light from a point is reflected in diverging lines.* Fig. 172.

(2.) Plane surfaces more or less rough : *light partly reflected, but more and more scattered as the surface is more and more rough.*

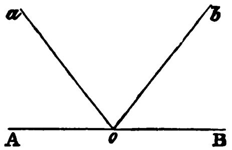


Fig. 172.

(3.) Curved surfaces more or less rough : *light partly reflected, but more and more scattered as the surface is more and more rough.*

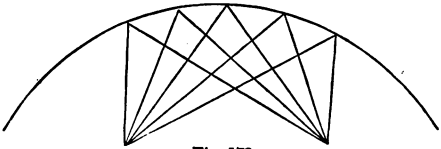


Fig. 173.

(4.) Curved surfaces perfectly smooth : *curved mirrors, from which light is reflected in converging lines if the surface be concave, but widely diverging if the surface be convex.*

Plane mirrors reflect light in a manner between the reflection

of convex mirrors and that of concave. Thus in concave mirrors the reflected rays of light converge; in plane mirrors they diverge slightly; in convex mirrors they diverge much.

There are, however, two cases of concave mirrors that deserve especial notice.

In a circle, a light at the centre would throw rays at right angles upon every point of the centre, and these rays would be reflected along the same lines to the centre again. If, instead of a whole circle, any part of one be taken, so much of the light at the centre as fell on it would be reflected to the centre.

If instead of a circle I take a hollow sphere and place a light at the centre, every ray of light will fall on the inner surface at right angles to it, and will be reflected to the centre. If instead of a sphere I take any portion of one, such as a watch-glass might be, all light falling upon the concave surface of this from a source at the centre would be in the same way reflected to that centre.

So that if a concave mirror be a portion of a sphere, however large or small a portion, it may be placed so as to reflect all light falling on it from a single source, back to the point whence it proceeds.

If such a mirror be a portion of a parabola—*i.e.*, so that every section of it shall be a part of a parabolic curve—then the light falling on it from the focus will be reflected in lines parallel to each other and to the axis of the mirror; *i.e.*, to the line joining the focus and the central point of the mirror. Also several rays of light parallel to each other and to the axis of the mirror falling upon such a mirror would be reflected convergently to the focus.

These two properties of a parabolic mirror may be combined so as to transfer light from one place to another in a very remarkable manner. Thus, a light being at one point, I hold a parabolic mirror so that this point shall be its focus. The light then falling on the mirror is reflected in parallel lines. By turning the mirror round the light, still keeping it at the same distance, so that the light shall still be the focus, I can send these parallel lines in any direction I please.

I now hold another mirror of the same kind near the point to which I wish to transfer the light, and so that this point is the focus of the mirror. Then all light falling in lines parallel to the axis of this mirror will be reflected to the focus.

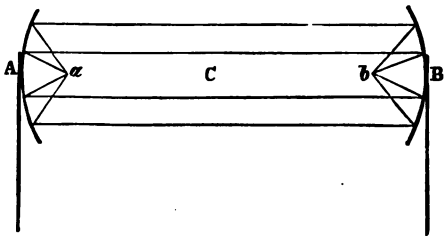


Fig. 174.

Let it be required to transfer heat or light from the point a to the point b, I place the parabolic

reflector A so that its focus is at a, and the parabolic reflector B so that its focus is at b; the two, A and B, facing each other. By this arrangement I can transfer light, heat, or even slight sounds, from a to b, or from b to a.

So that I have one mirror which will reflect the rays of the light at its focus in parallel straight lines, and another mirror that will receive these parallel lines and reflect them to *its* focus. All that I have to do is to hold the two mirrors so as to have, for the two foci, the points from and to which I wish to convey the light, and also that they are opposite each other, so that the parallel lines from one will fall on the other.

We may therefore classify mirrors somewhat thus :—

Plane. . . . . . *Curved.*

Convex. *Concave.*

Parabolic. *Other curves.* *Spherical.*

By concave mirrors light is generally converged; by parabolic mirrors it is reflected in parallel lines; by plane mirrors it is diverged in a slight degree; by convex mirrors it is diverged much more.

Thus, light falling on a convex mirror is deflected more than from a plane mirror, because from a convex surface the perpendicular lines themselves diverge, and the directions of rays of light reflected are determined by the directions of the perpendiculars from the same points.

If the mirror be a good one, the light reflected will convey to any one receiving it an image of the object from which the light comes, but the image will seem to be in a place altogether different from that of the reality.

Thus, in a plane mirror, such as an ordinary looking-glass, I see my features apparently behind the mirror, because the light falling on the glass from my face comes back to my eyes from the glass, forming therein an image of my face. But the image is formed in my eyes just as it would be in the eyes of any one standing in my place if the glass were taken away and I stood behind where it had been. That is, I see myself in the line in which the light comes to me. To revert to my illustration of a ball striking against a post and rebounding: if a ball be thrown against a tree, and, rebounding, strikes me, the impression on my mind is as if

the ball had been thrown from behind the tree. So if I see the image of any object by means of light reflected from a mirror, I have the idea of it being as far behind the mirror as it is really in front of it.

But in all case of plane reflection, where the surface reflected be parallel to the mirror, change of position is the only respect in which the image is deceptive. If the mirror be at right angles to the object, its position will be reversed. It must be borne in mind that we see the image in the mirror by exactly the same means that we see the reality. Thus we see the reality by means of vibrations of light coming from the object to our eyes; while we see the image in the mirror by means of similar vibrations which the mirror bends back from their original direction and sends also to our eyes. In all respects as to size, proportion, colour—in fact, in all but direction—the two images are identical.

But if the mirror be curved, other differences besides that of direction will be the result of reflection, owing to the divergence or convergence of the reflected rays. If, however, the object reflected be very small, such as a bright speck of light, and near the mirror, this divergence or convergence will not affect the image; but if it be of any size, or distant, the rays falling on the mirror from the different points of it, though they fall parallel, will not be reflected parallel, because they fall on different points of the mirror, and at each point will be reflected according to the law of reflection. Since the perpendiculars to a curved surface either converge or diverge, so will the reflected rays whose directions are governed by these perpendiculars.

In the case of an object seen by reflection, it appears to be behind the mirror, each point being seen in the direction of the reflected ray, produced nearly as far behind the mirror as the object is in front. Now if these reflected rays diverge in front of the mirror, they would converge behind; and if they converge in front, they would diverge behind. Also, rays divergent in front would, after converging to a point behind, diverge again; and in this case the image will be reversed—*i.e.*, the left will seem to be the right, and the right the left.

Therefore images seen by reflection in a concave mirror will be enlarged in size, while those seen in a convex mirror will be diminished, and, if the mirror be very convex, will be reversed in position, because the widely diverging rays will appear to meet and diverge crosswise before they seem to get as far behind as the object is in front.

This will explain the reflected images seen in metal dish-covers, coffee-pots, &c., however grotesque these may be. Given any reflecting surface and any object in front of it, it is easy to trace the directions of the rays of light falling on and reflected by the mirror, and the position and proportionate size of the image apparently behind it. This is equally true of circular and parabolic mirrors as of all others. Light falling on these is reflected

in exactly the same manner, and in obedience to exactly the same laws, as from other mirrors. The specialty of these two forms is not a special manner of reflection, but one that results from the ordinary laws being observed. In a spherical mirror the ordinary law results in reflection to the centre only when the centre is the position of the light. In the parabola the ordinary law of reflection, being observed as usual, results in the light rays being reflected in parallel lines, if the light come from the focus; or in being converged to the focus, if falling in rays parallel to the axis.

(9.) **Refraction.**—But if for the metallic substances, so smooth as to act as mirrors, I substitute substances of exactly the same size and shape, but transparent, such as glass, ice, &c., the light will not be reflected, but will pass through and continue its course, though this course will be affected by the passage. That is, the light, instead of being reflected, will be refracted, and therefore its course will depend not only upon the surface, but upon the thickness of the substance, upon its shape, and upon its refractive power.

In reflection the surface only is concerned; in refraction the surface is of little moment. A metallic mirror will reflect according to the smoothness and shape of its surface, from which the light glances as water from a rock, no matter how thin, or irregular, or rough the general mass may be.

In refraction, each ray of light enters at once into the substance upon which it falls. The thicker this is, the more its direction is changed. If the opposite surfaces be parallel, all rays are equally changed in direction; but if not, each ray is changed more or less according to the distance it has to traverse, and is more or less decomposed (p. 116). The amount of change in any given thickness depends upon the nature of the substance. Thus water refracts more than ice, alcohol more than water, phosphorus more than alcohol, and diamond most of all. I have spoken at length of Refraction elsewhere in the book, and only mention it here to show its relation to Reflection.

(10.) **Formation of Images by Lenses.**—But if a transparent body be made symmetrical, we can easily obtain, by means of light transmitted through it, an image of the object from which the light proceeds, just as we do by reflected light. But while in reflection the eye and object seen are both on the same side of the mirror, in refraction the transparent substance is between them. That is, light is *reflected from* the reflecting substance, and is *refracted through* the refracting body.

We have seen that a plane mirror reflects a ray of light. A plane lens transmits it in very nearly its original direction, and parallel to that direction, the distance of its new from its original direction depending upon the nature and thickness of the lens.

By a *lens* I mean a piece of the refracting substance; by a *plane lens*, a piece having its two surfaces parallel.

If the lens vary in thickness, the rays falling on the thicker part will be more refracted than those falling on the thinner portion (always excepting rays falling *perpendicularly* on the lens, which continue their path unchanged, whether the lens be thick or thin), and will also have their direction definitely changed.

These facts make lenses useful in optical instruments such as microscopes and telescopes. Thus by making my lens thick in the middle and tapering off regularly, so as to form a double convex surface, lines of light falling perpendicularly on one side are converged to a point on the other side; and my eye placed at this point receives thus much more light than it would without the interposition of the lens.

Fig. 175 shows how the light radiating from A is converged to B by the interposition of the lens between A and B.

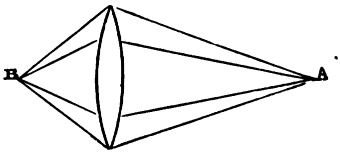


Fig. 175.

Generally, if a lens be thicker at one side than the other, the light passing through the thin end converges to the line passing through the thicker part. If I put two such lenses together by the thick ends, the light passing through the two thin ends will converge to the middle line. A double convex lens is, as it were, a series of such lenses, and the light passing through it converges to the central ray, so that such a lens brings the light from a large circular area to a central point where the eye can receive the whole.

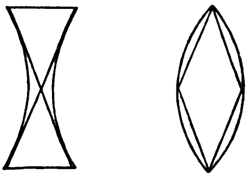


Fig. 176.

Fig. 176 shows how lenses may be considered as combinations of prisms.

Lenses are made of many shapes. Some have both surfaces alike, others different. The most common forms are—

Double convex—*both surfaces being convex.*
Double concave—*both surfaces being concave.*
Plano-concave—*one surface concave, the other plane.*
Plano-convex—*one surface convex, the other plane.*
Spherical—*the lens being a sphere.*
Meniscus—*one surface concave, the other convex; but one of these, the convex, being more curved than the other, the lens, if large enough, comes to a sharp edge.*
Concavo-convex—*the reverse of the above, the concave being the more curved, so that the larger the lens the thicker the edge becomes.*

These different kinds of lenses may be grouped together in any required number or manner; and since each affects all light falling on it according to its nature, without reference to the others, they may be grouped so as to produce most surprising effects. Perhaps no sense is so capable of being deceived as that of sight. We always *see* an object in the direction from which the light comes to our eye, and since the direction of a ray of light may be turned again and again in most remarkable ways, the most extraordinary optical delusions are possible by the aid of a few pieces of glass. It is quite easy to make it appear that the nose on a human face is a depression therein, or that the inside of a hat is the outside, and the outside the inside.

Just as by reflection the rays of light from the various points of any object may be regularly reflected, and so kept together as to still represent the image of the object, so by refraction the same result may be obtained. When I look *through* an opera-glass, I see images by *refracted* light. When I look *into* a mirror, I see images by *reflected* light. In both cases the transfer of the rays of light is so regular that all the rays from any given object are kept together, and continue to represent the image of the object.

(11.) **Reflection and Refraction combined.**—But reflection is not confined to mirrors so called. Glass, which is a very transparent substance, and which refracts light, also reflects it, and this from both surfaces. Thus light from a given object falls on an ordinary eye-glass, and part of it is reflected from the first surface, the remainder passes through the glass; and again part of it is reflected from the second surface (or rather from the surface of the air behind it), and passes back through the glass to our eyes. The remainder of the light passes on through the air, or whatever may be behind the glass.

Thus I get, from a common eye-glass, two images by reflection, although glass is called a transparent and not a reflecting substance. It may be said, as a general law, that whenever light falls upon any substance, some at least of it is reflected.

One day this summer, walking on the side of a hill near Ryde, overlooking the sea, with the sun just setting behind a row of trees, between the trunks of which it shone brightly, I held a common eye-glass so that the sunlight fell on it. Looking into the glass with my back towards the sun, I saw by reflected light two perfect images of the row of trees and the sun behind them—as pretty pictures as one could wish to see, one reflected from each surface of the glass; and in addition I saw by refracted (or transmitted) light the grass of the field in which I was walking. So that three sets of images came at the same time from the same glass to my eye. The sunlight fell upon the glass from between the trees, which were thrown in shadow. Some of this light was reflected from the first surface, forming one image; another was

formed by the light that, after passing through the glass, was reflected back through the glass from the surface of the air behind it; the remainder of the light, passing through the glass and the air, fell upon the grass, was partly reflected from it back through the air and the glass to my eye, but now gave an image of the grass instead of the sun, being, as it were, rearranged by the grass.

A few days afterwards I saw another beautiful example of the same kind, in the Queen's schools at Whippingham, near Osborne. A few squares of coloured glass are placed at each end of the schoolroom. Part are yellow, and part blue. Holding, as before, the glass so that the light coming through the coloured glass fell on it, I saw two reflected images, and a third by transmission. But in one point there was a great difference between the two images of the sun and of the window. The two pictures of the sun and trees were of nearly the same size. But of the coloured window one image was complete in the centre of the glass, while the other was on so large a scale that about an eighth part of the window covered the whole glass. In the one case the light came direct from the sun, and the refraction of the light forming the second image was but slight, so that both pictures were nearly alike; in the other the light came only a few feet, and the refraction (though of course no more than in the other instance) had a different ratio to the distance the rays had come.

I was much nearer one of these windows than the other. From the more distant one the second reflected image was very feeble. But when I placed my coat-sleeve close behind it, it was much more distinct, and not only the window but the whole of the schoolroom, from which light could fall on the glass, was seen in perfect miniature, with a clearness almost incredible by those who have never seen such a case of reflection. In this case the remainder of the light passing through the glass was absorbed by the black cloth of the coat, so that none of it was reflected back through the glass to interfere with the image formed by the light reflected from the glass, which was thus seen in perfection.

That black cloth is an absorber of light may be easily shown thus: I take an ordinary finger-ring, and place it so that the light of a candle, or any single source of light, falls upon the inner surface. From this light will be reflected according to the general law, the angles of incidence and reflection being equal, and these lines of reflection will cross in a series of points forming a cusp-like disc of light. If placed on a white table-cover, or on white paper, the effect is very pretty. I place it on my sleeve, and the reflected light is almost entirely absorbed. Just the line of special brightness (where the lines cross in the series of points I have already spoken of) is faintly visible, and will at first probably be mistaken for a thread or hair lying on the cloth, even by those who are looking for the light-rays.

I mention these three little instances, because I wish to show

clearly that expensive apparatus and deep learning are not indispensable for observation of the facts of nature, but that by means of ordinary everyday objects lying ready to our hand in a thousand ways we may easily enjoy some of the most beautiful phænomena, and so learn that it is not in the study or in books, so much as in the world and by using our senses, that we can really understand what is meant by "Physics."

That light is reflected from each surface of glass is easily shown by experiment. Hold the head or point of a pin close to a looking-glass, and you will see two reflections of it, one much clearer than the other, and separated by the thickness of the glass. The clearer image will be seen to come from the second surface. Hold a lighted candle in the same position, and two images will be seen as before. Look at these images first perpendicularly to the glass, and then gradually move the eyes sideways until you look *along* the surface of the glass. As you move the eyes you will find the front image grow, and the hinder one decrease, in brightness, until the front is the brighter of the two.

(12.) **Achromatism.**—We have seen that light passing through a prism is refracted. But refraction is not confined to prisms. It is produced by the fact that light passes through a body whose sides are not parallel. A concave or convex lens is such a body, and light is refracted when passing through such a lens. We use lenses because they refract light, and so enable us to collect light into a focus. But this, which is the real value of lenses, is accompanied by the fact that they also decompose light, and thus for a long time all images in telescopes and microscopes were coloured, and this in a very serious manner marred the usefulness of these instruments.

A lense is really a combination of prisms. Thus if I put together two prisms, base to base, I have a lens, the property of which is to converge rays of light falling on it. If I put together two prisms apex to apex, I have a concave prism, the property of which is to cause light falling on it to diverge. But lenses are bounded, not by straight, but by curved lines. They may, however, be still considered as combinations of prisms. In figs. 177 and 178 the straight lines represent the prisms, and the curved lines the lenses, so far as they vary in form from the prisms.

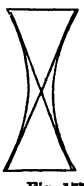


Fig. 177.

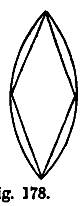


Fig. 178.

Light falling on a lens is therefore decomposed as well as refracted, so that all images seen through lenses are coloured. This, however, is now corrected by the use of *achromatic* lenses. There are compound lenses, in which the colour produced by one lens is removed by another. To understand how this is done, it is

necessary to distinguish clearly between *refraction* and *dispersion*.

In figs. 179, 180, the ray of light, o, falling upon a prism A, is refracted so that the central line of the spectrum falls on a screen at a, and the spectrum itself reaches from b to c. I now substitute the prism A′, and find that though the central line of the spectrum falls on a', the spectrum itself reaches from b' to c'—*i.e.*, it covers much less of the screen than before. The amount of the *refraction* is measured by the divergence of the central line A a from the original line of direction A m, while the *dispersion* is measured by the amount of space covered by the whole spectrum. Bearing in mind this distinction between refraction and dispersion, it is not difficult to comprehend the action of an achromatic lens.

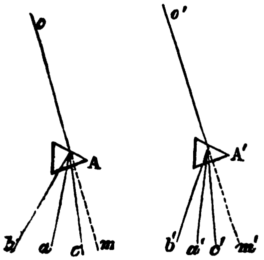


Fig. 179. Fig. 180.

Assuming AB, fig. 181, to be a lens (which may be considered to be made up of two prisms), light falling on it will be brought to a focus at m; *i.e.*, the middle line of the two spectra will meet there. But the focus of the violet rays will be at v, and of the red rays

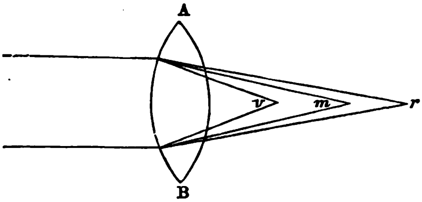


Fig. 181.

at r; *i.e.*, the spectra will extend from v to r, the orange, yellow, blue, &c., rays meeting between these points. If I place beside AB another lens of the same material, but of a shape to recompose the light, I also counteract the refraction, and so get no image at all, since the light will not converge.

But if I can find a lens of some other material that, with the *same refractive power*, has a *different dispersive power* (*i.e.*, that while it gives the same direction for the middle line m brings the ends of the spectrum closer together), I can so arrange such two lenses as to get an image that shall not be coloured. The light which is refracted and dispersed by one lens will have its dispersion, but not its refraction, counteracted by the other.

(13.) **Interference of Light.**—Assuming light to be motion

and not *matter*, it should follow that it is subject to all the laws of motion, and amongst others to the law that two equal and opposite motions destroy each other. Thus if a "motion" from A to B constitutes light, and another motion from B to A, also by itself constituting light, happen at the same time, will the result be mutual destruction, and will there be no light? On the other hand, if two such vibrations come together, so that, instead of destroying each other, their mechanical result ought to be a mutual strengthening, will there be more light? To both questions the answer seems to be "yes." Light can be made to destroy light; it can also be made to increase it. The illustration of this is somewhat difficult, because it requires the mutual action of two rays of light to be freed from all other interference. But that there are such increases and diminutions is roughly shown by placing a double-convex glass upon a sheet of paper. The half of the lens near to the light will appear dark, while the other half will be most singularly marked with lobe-like spots of darkness, apparently emitting rays of light, marked by fine dark lines. These variations are owing to the interference of the rays of light with each other, and the interference is owing to the divergence between the surface of the paper and that of the lens, the distance between them constantly increasing from the centre of the lens to the circumference.

Colour is but very faintly discernible in this very simple experiment, but there are slight tinges of colour at the edges of the bright rays. Two rays of light may destroy each other, just as two men running against each come to a stand; they may also intensify each other, or rather combine to produce one ray brighter than either. But between these two limits are numberless other mutual effects.

Two equal and opposite forces destroy each other: acting in the same direction, they combine to make a third force greater than either. Moving in different directions that intersect, the result of their meeting is to produce a third force, that in direction and amount is compounded of the other two, being what remains of their combined force after the deduction of what is destroyed by the mutual opposition. This proposition is true of all forces. If light be a force, it is also true of light.

But the variations between light and darkness, between white and black, are colours. When two rays of light intersect each other, they neither wholly destroy nor wholly intensify each other, but produce, by intermediate action, varieties of colour.

As illustrations of this, place two pieces of glass together, but having at one side some interposed substance, such as a wafer. The effect of this will be to place the glasses at a very acute angle to each other. Light falling on this would be reflected from both sides of the film of air enclosed between the plates. Thus, let A B and A C, fig. 182, be the two plates of glass jointed at A. A ray of light *a* falls on A B at the point *b*, and is partially reflected in the

direction $b\ o$, partly transmitted in the direction $b\ d$. Arrived at c on the second plate A C, it is again partially reflected in the direction $c\ m$, and partially transmitted in the direction $c\ d$. The reflected ray $c\ e$ comes in contact at e with the ray $n\ e$, and is in the same direction as the ray $e\ m$, the reflected portion of the ray $n\ e$.

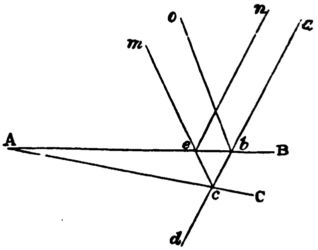


Fig. 182.

We have now two rays of light, or vibrations, moving in the same line. Will the result be increased light or darkness? This depends entirely upon the distance $c\ e$. If there be *any* complete number of waves of light in this distance, the motion of the two vibrations will *coincide* (since a wave of each will commence at e), and the result will be increased light. But if there be not a complete number of vibrations in $c\ e$, there will be *interference* and not *coincidence* of two waves, and the result will be either darkness or colour, accordingly as one wave destroys or only modifies the other; also $c\ e$ and $b\ o$ are not quite parallel.

Since the distance between the two plates increases from 0 at A regularly towards the open side B C, therefore there will be a certain number of points at which there will be coincidence, and between these all degrees of interference. There will therefore be lines of light and lines of colour.

But if, instead of two pieces of flat glass, I put together two lenses, one convex and the other flat, I get precisely the same arrangement as before, but in a more complete form. The central points which are in contact represent the jointed part A; and I have, instead of lines, circles of light and colour.

Many other examples of interference may be mentioned. Thus light admitted by two small holes (near each other) into a small dark chamber will produce intervals of light and darkness, while if one of the holes be closed the other will admit a simple ray of ordinary light. The pretty gradations of colour shown by some shells, and other substances having smooth but not truly flat surfaces, are also owing to this property of interference. A surface that is truly flat will become iridescent if it be marked with parallel scratches sufficiently near each to produce interference, and regular enough to prevent the light being merely scattered. The colours of soap-bubbles are also to be attributed to this source, the irregular thickness of the film being the cause. This last example will serve to remind us of what very small measurements we speak when we speak of differences of thickness producing interference.

SUMMARY.

(1.) Rays of light, heat, or sound, are more or less reflected, or bent back at every change of the vibrating medium. Page 285.

(2.) Rays falling upon parabolic surfaces are reflected in *parallel* straight lines. Page 286.

(3.) Polished metal surfaces, or crystals, are examples of reflecting bodies. Page 287.

(4.) Rays of light regularly reflected may be converged so as to produce an image of the radiating body. Page 288.

(5.) Reflection of light may be utilised as a means of measurement for very small distances. Page 289.

(6.) Heat, light, and sound are all reflected according to the same laws. Page 290.

(7.) The same ray may be reflected and re-reflected any number of times, if it fall successively upon several reflecting surfaces. Page 292.

(8.) Rays reflected from convex surfaces are divergent: rays reflected from concave surfaces are convergent, except when the concave surface is parabolic. Page 294.

(9.) Refraction is a phase of reflection, but the force passes through instead of being bent back. Page 298.

(10.) Rays passing through lenses, may be converged so as to present an image of the radiating body. Page 298.

(11.) Images are also obtained by combined refraction and reflection. Page 301.

(12.) Such images are sometimes tinged with colours not belonging to the original image: these colours may be removed by using a series of lenses. Page 303.

(13.) Colour is also produced by the interference of two reflected rays. Page 304.

REFRACTION.

(1.) **Introduction.**—Light, heat, or sound, falling upon a polished metal surface, is, as we have seen, reflected. If I substitute for the metal plate a glass screen, the light will still be reflected, but will be much less so than before, the greater part passing through the glass. We speak of glass especially as being transparent, or translucent, because light passes so readily through it, and continues its course on the other side.

But just as in reflection the vibration is turned from its course, so is it in *refraction* (which is the name given to the influence of any substance through which it passes); but while in reflection the surface only is concerned, in refraction the amount of influence depends on the thickness and nature of the medium. Also, in reflection the vibration returns, more or less, towards its starting-point; in refraction it continues its course, but, more or less, to the right or left of the original direction.

But the greatest or most important result of refraction is the breaking up of light into its constituent parts. To any one who does not know it, and especially to any one unaccustomed to scientific study, it must be doubtless a great surprise to be told that light is a compound vibration, made up of several vibrations, each having its particular rate and extent of motion. It is a little difficult to realise what this means—to imagine a number of vibrations travelling side by side, differing in extent, in speed, and therefore in the effect produced by them on the mind, yet so harmoniously blended, so perfect in their arrangement, that the impression made on the mind by their united action is that of a simple and complete picture—so simple and so complete, that for centuries after centuries no suspicion of its complexity was entertained.

Our first impression of light is that of a perfectly pure, perfectly white, perfectly transparent *something* that enables us to see. If we are told that all light is *coloured* and none white, or rather that all light conveys the impression of colour, and that we get the notion of whiteness only by the union of several different lights

or vibrations, the assertion probably seems as absurd as it is incredible to an ordinary person who has not had his attention directed to the study of natural facts. But it is nevertheless believed that it is so. We may obtain some idea of this compound yet apparently simple nature of light if we can imagine a bundle of very fine rods of different thicknesses bound together very closely, so as to make apparently but one wire. Further, we should imagine these wires all travelling *endways* with immense rapidity, yet each with a different velocity, though the slowest moves with such amazing rapidity that the difference between it and even the fastest is as nothing in comparison. Further, let us imagine each wire to be a different colour, but that the effect produced by the presence of all is that of white—*i.e.*, that all these colours mixed together appear white. By bearing in mind these three theories—1. That a ray of light apparently simple is made up of several rays bound together so as to seem but one; 2. That their component rays are of different colours, but, when compounded, appear of but one colour, and that white; and, lastly, 3. That these rays travel with different velocities, though even the slowest moves at a speed altogether beyond comprehension,—we may follow very well the theory of refraction.

(2.) **Refraction according to the Theory of Light being Compound.**—We have just seen that light or heat falling upon bodies which they can penetrate, do pass through, more or less, but have in the passage their direction affected. If the two surfaces of the substance so passed through be parallel, the change of direction is the only change; but if they be not parallel, the component vibrations are unequally affected, and consequently take separate directions. The light is no longer white, but each ray is visible separately, and has its own special colour. This may be roughly illustrated by throwing a compound ball against a wall; thus I tie up several shot or small marbles in a thin covering, and throw them against a wall. If the covering does not break, they all rebound together as a simple ball; but if it break, each rebounds with a force and direction of its own. So with ordinary light: so long as its constituents are kept together they give the impression of a single ray of pure white light; but if, from any cause: they are separated, the impression conveyed to the mind is that of several rays of light, each distinct from the other by its different colour. The rays thus separated may be easily re-combined so as again to form a single ray of white light, by making the substance through which the rays pass of equal thickness throughout, so that its surface shall be parallel.

But a ray of light, on entering a piece of glass (or other transparent substance), cannot know whether or no the second surface be parallel to the first—cannot choose between mere change of *direction* and being broken up into its constituents; and it may *be safely* supposed that this refraction or separation of the coloured

rays commences immediately after light passes from one medium to a denser, but that if the two surfaces of the denser substance be parallel, then this refraction is compensated by a second and contrary effect, and the ray of white light is first decomposed and then recomposed, issuing from the second surface as completely a single ray as when it entered the first.

To understand this clearly it is indispensable to consider white light as a compound result, and as having no individual existence of its own. Though we take it to be a bundle of coloured rays so closely arranged together as to be but one in appearance and effect, we must suppose that each of these preserves its separate existence, and is as readily acted upon by external influence as if the others had no existence, and that white light is not a something made up of several coloured lights, but is the result of their presence in certain definite ratios.

If I arrange side by side a number of short sticks of wood, or bars of metal, both ends of each being supported by side bars, then the weakest will be protected by the stronger ones from the effect of any blow falling on all: but if I place them on a table so that one end of each project, then a blow falling on all will set each in motion, according to its particular weight. So with white light falling on a piece of glass, ice, or other transparent body—each particular ray of coloured light is affected by the contact according to its own velocity. Or we might consider it by means of another illustration. If I throw a number of marbles against a wall, each will rebound with a direction and a velocity governed by its direction and velocity in moving towards the wall. Though they may all reach the wall at the same moment, yet they will be affected individually, and not collectively, by impact with it. This illustration fails so far in that the marble is a definite body, having but one time of impact, whereas light may be regarded as a continuous stream. But we may get a more complete analogy thus: Imagine (or even construct) a number of tubes, ranged side by side, having water running through them, each stream having a definite and regular velocity different from the others. Let these fine streams of water, moving with different velocities, fall side by side upon a smooth surface (say of marble), and they will be reflected with greater or less force, and to a greater or less extent, according to their greater or less velocities. To an ordinary observer the various streams seem to be moving with equal rapidity, and represent the component rays of light; contact with the marble table detects the differences of forces, and reveals them by the difference in the distance to which they are reflected. In light, however, this is shown by the different *directions* in which the rays continue their courses after contact with a dense medium.

If the rays fall *perpendicularly* on a dense medium, the only result is to reduce their velocity, since the reflection is, as it were, directly back *again*, and they continue to move onward (with a

speed slightly less than before), but still compactly together. The difference of velocity produces no other effect than that of modifying the amount of reflection—*i.e.*, the ray moving the most rapidly is retarded the most, and that moving most slowly the least; but still this is slight by comparison, and this retardation produces no perceptible effect upon the general body of light, because each ray is continuous, so that at any point all are present or rather passing, at any given point of time.

It may help us to understand the refraction of light falling obliquely upon any substance, if we consider but one of the rays composing it. Imagine a long rod of metal falling endways, but obliquely, on a table. At whatever speed it might be moving, one edge of it would come into contact with the table before the other. If the rod were of soft material, this would tend to bend it at the point, so that when the opposite end reached the table, the tendency would be to enter the table in a direction slightly different from that in which the rod first moved, and one approximating more nearly to the perpendicular.

Light falling on a plate of glass is probably affected in some such manner, and this may be the real cause of the refraction. It must be recollected that light is not a thing, but a vibration,—does not pass through the glass, but sets either the glass or some ether within it in motion, in such a manner as to carry forward the vibration. If the glass or ether be so acted on, this action will naturally continue in the straight line in which it is communicated, without reference to the line in which it previously came. The amount of such deflection will be affected by the velocity of the ray; and since each ray has a velocity peculiar to itself, each will be deflected to an amount peculiar to itself; and thus, after impinging obliquely on any dense substance, a ray of light will have its constituent coloured rays dispersed, as it were, so as to continue their courses through the substance on which they fall, not as white light, but as a number of independent coloured rays, diverging from the point of incidence, and becoming more and more separated as the thickness of the substance increases.

If we try the experiment with a triangular wedge of glass (usually called a prism), we shall find that light falling on this prism as ordinary white light is thus broken up, and passes off from it as independent coloured rays, each having its own course. The colours of the rays are a quite distinct consequence from the change of direction. They are not *produced* by this refraction, but *become evident* because each ray is isolated, so that its colour is no longer affected by the colours of the other rays. The colour of each ray is just as much present, and as visible, in white light, as when the ray is by itself; but the colours, when they fall together on the eye in the number and ratios in which they exist in ordinary light, give the impression of white only, so that white may be said to be compounded of all colours. In semi-scientific

language white and black are said not to be colours at all; and this is considered to be justified by the fact that white is not an independent colour, but is obtained only by the mixture of all the primary colours in a definite ratio—while black may be said to be the absence of all colour.

We see, then, that white light falling upon a dense but transparent substance, such as glass, is broken up, and passes out from the other side as a number of independent and divergent coloured rays. It follows from this, therefore, that light entering a room through an ordinary window should be thus decomposed, and that our rooms and furniture should be lit up with all the colours of the rainbow; but we know that nothing of the kind occurs, and that light passes through the glass of our windows without the slightest change of colour, and apparently as freely and completely as if through air. This is considered to be owing to the fact that the glass in our windows is of uniform thickness, and consequently has its surface parallel; and when light falls on a transparent substance with parallel surfaces, whatever decomposition it undergoes on entering, seems to be compensated by a recomposition on leaving, so that the light leaves the second surface as compactly composite as when it falls on the first.

This is usually explained by considering such substance of uniform thickness as being practically made up of two prisms, the second of which recomposes the light broken up by the first. Considering each ray of light by itself, it is evident that the same cause which deflects the ray *towards the perpendicular* when entering a denser body, will deflect it *from the perpendicular* when it passes from the denser substance into the air again.

Thus, passing obliquely through the glass (or whatever the body may be composed of), one edge of the ray (*i.e.*, one extremity of the vibration) will reach the air before the opposite one, round which second edge (being retarded) it will, as it were, describe a small arc of a circle, so that the ray will go on through the air, not exactly in the same line in which it traversed the glass, but in one slightly more inclined from the perpendicular. These two deflections compensate each other when the two surfaces are parallel, so that the light passes away in a direction parallel to that of its incidence, and distant from it more or less according to the thickness of the refracting body.

Heat and sound are both refracted in exactly the same manner, and according to the same laws, as light, excepting that there does not seem to be any decomposition of either heat or sound—*i. e.*, the only result of refraction is to change the direction of the rays. It may be that heat and sound are simple vibrations, and therefore incapable of decomposition; or that the decomposition, if there be any, is not perceptible by our senses. If all light were white, we should know but little, if anything, of its decomposition. Or it may be that light, as well as heat and sound, is also a simple

vibration, and that the "decomposition" into coloured rays is explicable by another theory than the one usually held.

(3.) **Theory of Refraction according to the Theory of Light being Simple.**—In the darkest cellar it is quite possible to get the sensation of light without any reference to sunlight or even combustion. It is quite possible, by merely rubbing the eyes, to produce the sensation of light. A sudden blow is known to have the same power. So that it is not necessary to have the compound light of the sun's rays to produce the sensation, which seems to depend entirely upon the presence of motion in the optic nerve. Might we not, therefore, imagine that colour depended entirely upon the amount and direction of this motion?—that it depended, not upon the number of independent vibrations, but upon the character of one?

What would refraction mean if this be the theory? It could no longer be the *decomposition* of light, or the *separation* of its constituent rays. It would mean that the velocity and direction of the simple vibration producing light were altered, and that this alteration produced the alteration in the sensation which we call colour. For it must be remembered that both light and colour exist in the optic nerve, and there only.

(4.) **Refraction through Bodies having Parallel Sides.**—In fig. 183 is shown a ray of light, A, falling upon four parallel transparent substances. It passes through air first, with a certain velocity in a certain direction. Falling upon a it has the direction changed. The atoms of a are more densely packed together than those of the air, and the direction of the light is changed from B to C; the atoms of b are supposed to be still more compact than those of a, and again the direction of the ray is changed from C to D; the still denser stratum c produces a further deviation from D to F; the last stratum d still further deflects the ray from D to E.

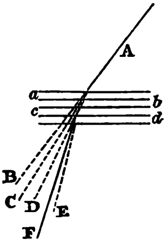


Fig. 183.

After passing through a, b, c, and d, the light emerges again into air; but in what direction? In that of F, which depends upon the density of the air into which the ray passes.

In fig. 195 is an example of refraction through one transparent substance only. The ray of light A o falling on the stratum between 0 and 0′ has its direction changed from A A′ to o o'; but on passing again into the air at o', has its direction changed from o o' to o' B, parallel to the original direction A A′. That is, the greater density in the transparent body has one effect when the light enters it, and this effect is exactly counterbalanced when the ray leaves it, by the less density of the air into which it passes. This assumes that the air on both sides of o o' is of the same

density. Two strata of air of different densities are as really two different bodies, and have the same kind of refractive power, as two liquids or two solids of different densities.

(5.) **Refraction through Prisms.**—So far we have discussed the *change of direction* owing to refraction through strata having parallel sides. Let us now consider what change will be produced in direction if the sides be not parallel.

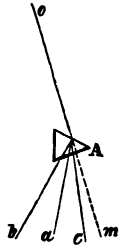


Fig. 184.

In fig. 184 the ray *o* falling on the prism A is not refracted in one line, but in several, as *c*, *a*, and *b*. To what can this be owing? It must be remembered that it is motion, not matter, that passes through; that some force impinging on one side of the prism sets its atoms in motion amongst themselves; that this motion passes from one side to the other; that it is transferred from the second face of the prism to the air.

It cannot be imagined that this force can pass from atom to atom of one row only through the body. It must affect other atoms that are in contact with these. If I arrange a number of marbles in a group, and shoot another marble at one of the outermost ones, it will disturb, more or less, most of the others, and the force, if strong enough, will pass right through the group, moving one or two of the outer ones on the opposite side away from the others. The number of these so detached, and their lines of motion, would illustrate better than diagrams the phenomena of refraction.

I have discussed this theory—if it deserve the name—in the final chapter.

(6.) **Dispersion by Refraction.**—In figs. 185 and 186 we see the same result of refraction — a spreading out a fan of light from the second surface of the prism, but in one the fan is much wider than in the other. The existence of the fan is due to refraction; the amount of it is called *dispersion*, the name assuming the existence of individual rays of coloured light, which are considered to be *dispersed* by the action of the prism. Returning to our figure of a group of marbles, we might say that in fig. 186 we have a greater number of atoms set in motion on the second side of the prism than we have in fig. 185.

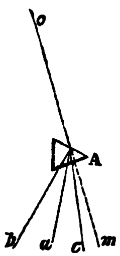


Fig. 185.

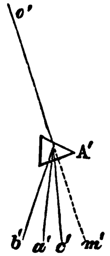


Fig. 186.

In fig. 187 we see how, by joining two prisms, base to base, we get two corresponding dispersions. If A B be a circular lens, we

shall get at v a violet-coloured image, at r a red image, and between other images, orange, yellow, green, and blue.

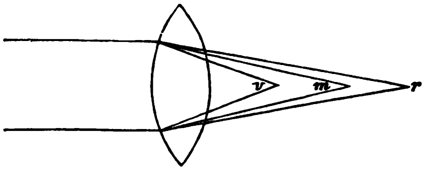


Fig. 187.

(7.) **Causes affecting Refraction.**—Refraction gives us two results—a change in the direction and in the character of the light refracted. The change in the direction may be considered capable of explanation by the ordinary principles of mechanical action. How shall we explain the phenomena of colour? Either we have produced many rays out of one, or have broken up a compound ray into its constituents. Whichever view may be the right one, we may ask, What conditions affect the amount of the change in direction, and the dispersion of the constituent or resultant rays?

1. Heat decreases the refraction and also the dispersion.
2. Density increases them.

These two are really the same, since heat and density are almost contradictory terms. If fig. 188 represent the atoms of a refracting body, it is easy to imagine that the nearer they are together, the more will any force acting on one be spread over the whole. Heat tends to separate these atoms; therefore the less heat the greater the density, the greater the number of atoms affected by any given force, and the greater the consequent radiation. So that a force acting at A will affect more and more of the atoms at B, as they are nearer and nearer together.

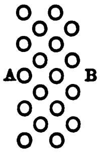


Fig. 188.

(8.) **Examples of Refraction.**—An ordinary eye-glass is a refracting instrument. Rays of light falling on its surface are diverted from their course. Fig. 189 shows how a double convex glass converges rays that would otherwise continue divergent. But we must bear in mind that in considering optical instruments, we must distinguish between the object as a whole, and its constituent parts. Thus we look through a telescope at a star, or through a microscope at a hair, and we get an image like the original in every respect but size. Whence comes this differ-

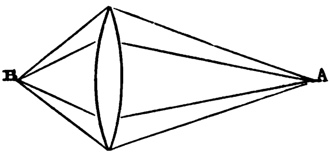


Fig. 189.

ence of size? From the fact that the object gives off light, not as a whole, but in a number of rays, travelling side by side, which may be separated, diverted, and re-combined at pleasure.

I place a dozen marbles in a circle, at distances of an inch apart. Light comes from these to my eyes, and I have the image of the circle; but this is formed by the circular arrangement of the rays of light from twelve distinct bodies. These twelve sets of rays can be converged by a *regular* lens so as to form, in my eye, the image of a circle of twelve marbles, a half, a quarter, or a tenth of an inch apart; or, by divergence, as a circle of twelve marbles, two, or even three, inches apart. But, by exactly the same process, the rays of light from each marble are also converged or diverged; so that the marbles are smaller as well as closer, or larger as well as farther apart.

To understand Refraction and Reflection, and the process by which we are able to alter the size of any image without changing it in any other respect, we must bear in mind two things: 1. That our visual conception of the size and shape of objects depends upon the effect produced on the eye by the light falling on it; that two things affecting the eye in the same way *seem* alike, however different they may be. And, 2. That the light proceeding from any object consists of an indefinite number of independent rays, each pursuing its own course; that it is the way in which these rays are grouped together, *at the moment they reach the eye*, that determines our conception of what they represent.

Examples of the rearrangement of these rays by what is called refraction are numerous and familiar. The tinges of colour given by the cut-glass drops of chandeliers, or by the sharp projections of cut-glass tumblers; the apparent change in the size of objects seen through eye-glasses or spectacles, microscopes or telescopes; the seeming bent condition of spoons, sticks, &c., in water;—these are all familiar examples of refraction, all owing to changes in either the direction or character of the rays of light which collectively make up the image.

(9.) **Total Reflection.**—This may be considered as an exam-

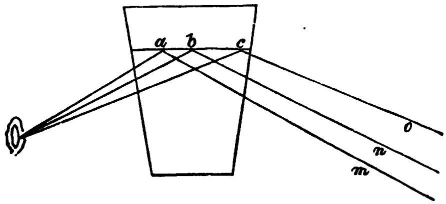


Fig. 190.

ple of reflection or of refraction. If of reflection, we have a ray of

light passing through a denser medium—water, to air—and being reflected from the surface of this second medium back through the denser; but here the law of reflection (that the angles of incidence and of reflection should be equal) is not observed; if of refraction, we have a necessary result of the law of refraction, that the perpendicular *a* (fig. 191) should be shorter than the perpendicular *b*; that is, that the line of incidence should be nearer the line of junction than the line of refraction.

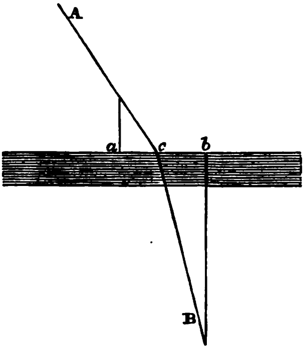
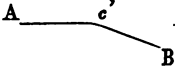
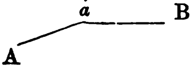


Fig. 191.

But when the line of incidence approaches nearer and nearer to this line of junction *a b*, and at last passes it, we have this law no longer. For when A *c* is coincident with the line of junction —*i. e.*, when the light travels along the top of the water, it will enter the water, making an angle A *c* B thus:



If the ray be considered to be continually depressed, so that it now passes upward through the water, as in fig. 190, the refracted ray will also continually approach the line of junction as the incident ray is depressed below it, until we have it emerging in the line of junction, as



But between these two positions, the one where the incident ray is coincident with the line of junction, and the other where the emergent line is so, we have a space in which the incident line (being below the junction, but not sufficiently so as to render the emergent line so high as the junction) produces a refracted ray that also passes through the denser medium, as in fig. 190.

If we preserve the distinction between reflection and refraction, it is evident that *total reflection* is really an example of refraction, and not of reflection; since the law of reflection does not hold good, while the law of refraction appears at first to do so. If we regard refraction and reflection as two phases of a comprehensive phenomenon, the total reflection is the border land where they meet.

(10.) **Law of Refraction.**—This is expressed by saying that *the ratio between the sines of the incident and refracted rays is always the same for the same substance.* To the reader who understands trigonometry, this statement is simple and clear; to others it may be explained by saying that it means the perpendicular *a* is always the same fraction of the perpendicular *b*, when *a c* is *equal to b c.* But this holds true for each substance separately.

In glass and air, in glass and water, in water and air, or in any two transparent media, it is always the same for the same media. This might at first seem no more than saying that the change of direction produced by one piece of glass, or one glass of water, was just the same as that produced by any other piece of glass, or glass of water, of the same size; and this would not excite much wonder or admiration. But it means more than this: it means that if, at any angle at which light falls, the line a is $\frac{1}{3}$, or $\frac{1}{4}$, or $\frac{1}{5}$ of the line b, that it will have the same ratio at any other angle, whether greater or smaller. If by depressing A c I shorten a by one-half, the ray c B would be raised so as to shorten B b one-half also.

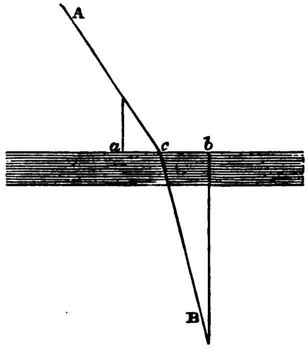


Fig. 192.

Some thoughtful reader may say that when A c is coincident with a c b, the line of junction, then a will be 0, while B b will still be a real distance; also that when the emergent ray c B is coincident with a c b, then B b will be 0, while a will be a real distance. But the law is for light passing from one medium to another, not for light continuing in the same medium.

(11.) **Nature of Refraction.**—Just as reflection is bending a ray of light, heat, or sound more or less back again towards the starting-point, so refraction is bending such ray more or less away from its direction. Roughly speaking, the distinction between reflection and refraction is, that in refraction the ray is affected by passing *through* a body, while in reflection it is affected by the surface only. The name refraction suggests the theory that light is broken up into its constituents.

SUMMARY.

Light, heat, or sound, passing through any body is affected more or less in direction, velocity, and wave-length. This is called *refraction*. Page 307.

White light, when refracted by prismatic bodies, is decomposed into its constituent coloured rays. Page 308.

Or it is so altered in its velocity and wave-length as to give the impression of colour. Page 311.

Light passing through bodies having parallel surfaces is only affected as to its direction, and not as to its colour. Page 312.

Some prismatic bodies *disperse* light more than others—*i.e.*, produce a longer spectrum. Page 313.

The amount of refraction is affected by changes of density or of temperature. Page 314.

An eye-glass, a microscope, a telescope, are examples of refractive apparatus. Page 314.

Total reflection is an example of refraction. Page 315.

Refraction is governed by fixed laws. Page 316.

Refraction is so called because it is supposed to *break up* light. Page 317.

TRANSMISSION.

(1.) **Introduction.**—We are so familiar with the passage of heat, light, or sound through air, and of light through glass, that these are often considered as matters of course. But they are as remarkable as any other phenomena, when really thought of. Why should light pass through glass, and not through wood or iron? When light does so pass through glass, what is really done? The source of light is on one side of the glass and our eyes on the other side; what effect does the glass produce on the rays of light? what effect do the rays of light produce on the glass?

If we assume the existence of an ether, then we must consider transmission to consist of the passage of the ether through the interstices of the glass; otherwise, we must assume the particles of glass themselves to vibrate, and thus transmit the light. In either case we must assume the glass to consist of particles arranged very regularly.

(2.) **Examples of Transmission.** — Sound is transmitted through almost any substance. Heat passes through rock-salt, sulphur, glass, and ice, in solids; through bisulphide of carbon, olive-oil, sulphuric acid, and water, in liquids; through air, oxygen, nitrogen, and hydrogen, in gases. In these enumerations I have placed first the substance that most readily allows the passage of heat—*i.e.*, rock-salt in solids, and bisulphide of carbon in liquids. All the four gases named appear to allow heat to pass through with equal completeness. Light passes through glass and horn in solids, water and many other liquids, and through gases, with great readiness.

We are so familiar with the transmission of light through glass, that we seldom stay to think how remarkable it is. We know that sound is conveyed by solids; but light is so much more delicate a vibration, so infinitely minute, that it is amazing to think that each pulsation is conveyed accurately and completely through

so solid a material as glass, a substance so compact that it keeps out every breath of air, every speck of dust.

Force is also transmitted in the form of electricity or magnetism; but not by the method of radiation, which we usually call transmission.

Heat, light, electricity, &c., are examples of the *form* in which force may be transmitted; so radiation, reflection, refraction, conduction, are examples of the *method* of transmission.

(3.) **Results of Transmission.**—The result of transmission is simply the transfer of force from one place to another. Radiation, reflection, refraction, are all examples of transmission; but the term transmission is used for the passage of heat, light, or sound, through a solid, liquid, or gaseous body, without reference to any change in character or direction, but only to amount. So that it simply means the transfer of so much force, either as light, heat, or sound, from one side of a given body to another.

(4.) **Nature of Transmission.**—The transmission of matter is always evidenced by the fact that it was here, and it is there; and it has been moved from one place to another. So the transmission of force is shown—it was here, and it is there. But just as a body that has changed its place must have passed through every point of the path along which it travelled, so transmission of a force implies a continuous medium of transmission. I cannot pull by means of a chain of which a single link is missing, nor push by a rod that is not continuous. Just so, a vibration cannot be transmitted across an absolute vacuum. Transmission of heat, light, or sound, is simply a continuous vibration: it may be the vibration of an ether, or of ordinary matter: the transmission may be between, or by means of, the particles of the familiar objects surrounding us; but it is the continuance of motion from particle to particle.

SUMMARY.

Force is transmitted from place to place in the same manner as matter. Page 319.

Light is transmitted through horn, glass, and air; heat through rock-salt, sulphur, glass, oil, water, and air; sound through most substances. Page 319.

The result of transmission of heat, light, sound, is the transfer of force from one place to another. Page 320.

Transmission of force is performed by the continuance of motion from particle to particle of the medium of transmission. Page 320.

POLARISATION.

(1.) **Introduction.**—The light falling from a candle upon a looking-glass divides into two rays, each reflecting an image of the candle. One of these comes from the first surface, and one from the second—*i.e.*, when the light falls on the glass, part of it is reflected and part refracted: one part is transmitted through the glass, and part back through the air; and the part passing through the glass falling on the mercury, is again divided, one part entering the mercury, the other being reflected. It depends upon the angle of incidence which of these reflected images shall be the more distinct. The smaller the angle between the ray and the surface, the more distinct the first image, and the less the second.

This is a simple example of one ray being divided into two, or rather of one ray producing two. Under certain circumstances these two rays, so produced from one, differ in very important points from each other. The questions to be answered are—1. What circumstances divide one ray into two? 2. What differences exist between these rays?

(2.) **Causes of Polarisation.**—(*a*) *Division of Ray.*—Iceland spar is transparent, so is tourmaline, so is glass; but the transparency of glass differs in a very important manner from that of spar or tourmaline. In well-made glass the particles are all at the same distance from each other; in spar or tourmaline these particles are more compressed in some directions than in others. The result is, that a single ray of light falling upon glass continues a single ray through the glass (not counting the reflected ray); while a single ray falling upon spar or tourmaline becomes a double ray—*i.e.*, *two rays passing through*, besides the reflected ray from the surface. This arises probably from the compression of the spar or tourmaline being greater in some directions than in others. A rough parallel may be indicated thus: Suppose water to be running through one pipe into another, and that at one place the substance of the pipe is very thin. If such thin

part be at a corner, so that the water impinges upon it, an opening will probably be made through which some of the water will pass, and so the one stream will be divided into two.

If, however, such weak place be at the side of the pipe, so that the water merely passes by, there will be much less chance of a rupture. Just so, if in its ordinary direction the refracted ray meets with a point where (from difference of density) the force finds another direction in which it can proceed, in obedience to the ordinary rules of refraction, as easily as in the normal direction, there will be, naturally, two rays instead of one.

(*b*) *Planes of Vibration.*—Therefore, we may say, the cause of polarisation, so far as the duality of the direction is concerned, is the variations of density in the refracting substance. We have then to consider what is the difference between the two rays, if there be a difference; and from what cause such difference arises? The difference is considered to be in the *plane* of the vibration. Thus, if we pour water through a circular pipe which opens into two others, both very flat, the one circular stream will divide into two flat streams. Just so an ordinary beam of light is considered to be vibrating on all sides (*not to and fro*, but *in and out* from a central core, as it were); but when polarised, to vibrate only in *one* plane. Thus, to continue our parallel of the circular and flat streams of water, let us take a cylindrical pipe 1 inch in diameter, and two flat pipes, also 1 inch one way but *very* thin, say $\frac{1}{16}$ of an inch, the other. Now, if I place the flat pipes on the ground, one flat, the other on edge, and pour water through the cylindrical pipe into the two flat pipes, I shall have the exact parallel of polarised light. A circular beam of light is broken up into two flat beams *at right angles to each other*, one being flat, the other edgeways on the ground.

Let us consider a *vertical* beam of light. This is believed to be vibrating to and from every point of the compass, north and south, east and west, north-east and south-west, north-west and south-east, &c. Such a ray, when polarised, is believed to be divided into two, one vibrating *only* north and south, the other *only* east and west; or one north-east and south-west, the other north-west and south-east. The exact directions of the resulting vibrations would depend upon circumstances, but there would be two rays of light, each vibrating *in one plane only*, and *at right angles to each other.*

But we must bear in mind that it is *not* the division of one ray into two or more rays that is meant by the term polarisation, but *the reduction of the planes of vibration to a single one.* The origin of the term is its use in magnetism. Just as a magnet is supposed to have two opposite poles, so the ray of light is supposed to have two opposite directions of vibration, and only two: up and down, right and left, north and south, as the case may be.

(3.) **Methods of Polarisation.**—(*a*) *By Reflection.*—Light

falling on glass is partly reflected, and more or less polarised. It is also partly refracted. When the refracted ray and the reflected ray are at right angles to each other, then the reflected ray is wholly polarised. That is, when the angle *o b d* is a right angle, the reflected ray *o b* is completely polarised. The vibrations of such a beam is then in one plane only, and that plane is parallel to the surface A B, which is the polarising surface.

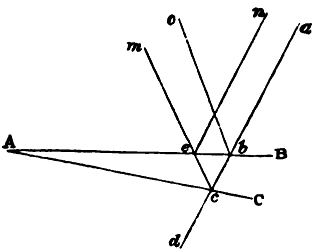


Fig. 193.

This relation between the reflected and refracted rays happens in the case of glass when the incident ray is at an angle of about 56°. If the substance refract more than glass, the angle must be greater for the reflected ray to make a right angle with the refracted. Thus, in a diamond, the angle is about 68°. If the refraction be less than in glass, the angle must also be less ; thus, in water, the angle is only a little over 50°.

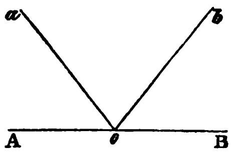


Fig. 194.

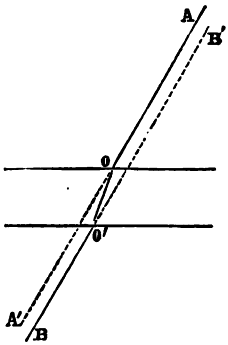


Fig. 195.

(*b*) *Polarisation by Refraction.*—The refracted portion of a beam of light is also polarised, more or less, but its plane of vibration is at right angles to that of the vibration of the reflected ray. If the reflected ray be wholly polarised, the refracted ray will be partially polarised, the quantities being equal. When they are at right angles one is completely polarised; when their angle is less than a right angle the polarisation of each is but partial.

When a ray *b o* falls on a plate of glass at an angle of 45°, it is reflected, also at 45°, in the ray *o a*. If it passed through the

glass in a straight line with the line of incidence, as A *o* A, fig. 194, then the reflected and refracted rays *o a* (fig. 194) and *o* A (fig. 195) would be at right angles, each being 45° with the surface. But the angle between these rays is increased by the small angle A *o o′*, so that the angle between the reflected and refracted rays is more than 90°.

But by depressing the line of incidence *b o* (fig. 195), I likewise depress *o a;* also I raise *o o′* (fig. 195), so that the refracted and reflected rays gradually approach each other. By this I compensate for the extra angle A *o o′*, and the two rays produced by the incident ray are at 90°, and then both are equally polarised.

Since the angle A *o o′* increases with the refracting power of the substance, the depression of the incident ray must also increase to compensate this. So that the polarising angle increases with the refractive index.

By means of the circular tube and two flat tubes already mentioned (p. 322), I could construct a rough model of the three rays, incident, reflected, and polarised, of total polarisation. Thus the circular tube placed at the proper angle would represent the incident ray vibrating in all directions around its path; one flat tube, placed so as to make an equal angle with the vertical line, would represent the reflected ray vibrating only from side to side, parallel with the reflecting surface; the second flat tube, placed at right angles with the first one, and therefore at the proper refracting angle with the circular tube, would represent the refracted ray, vibrating only up and down, perpendicular to the surface of the refracting body, and to the vibrations of the reflected ray.

(4.) **Results of Polarisation.**—If a polarised ray of light fall upon a second plate of glass, the result will depend upon the angle of incidence and the position of the glass with respect to the plane of vibration. If the mirror be at the polarising angle (so that the reflected and refracted rays are at 90°), then in one position, when the two mirrors are parallel, the amount reflected is the greatest, and that refracted least—*i.e.*, more of the light is reflected than at any other position. In this position the vibrations of the polarised ray are parallel to both mirrors, and the ray falls sideways, as it were, on the second mirror. If I use the flat pipe before spoken of to represent the ray, it will rest with its flat side on each glass. If now I turn the upper mirror 90°, it is no longer parallel to the lower, and the *end* of the vibration, not its side, strikes its surface—*i.e.*, the upper mirror would rest on the *edge* of the thin pipe, and not upon the side. In this position the polarised ray is considered to be *wholly transmitted*, and not at all reflected.

As I turn the upper mirror from the position parallel to that at right angles to the lower, the reflected ray decreases in intensity gradually, and at last vanishes; but if I continue turning the *mirror*, the reflected ray gradually increases, until, after passing

its maximum, it again decreases,—the increase and decrease depending entirely upon whether the ray impinges upon the mirror more or less sideways.

A rough illustration of this may be shown by striking a stick on some moderately compact body, first lengthways and then endways. Thus I could force a stick through thin ice much more readily by pushing it endways than by throwing it down sideways. So, again, the hand meets less resistance if put into water edgeways than if pressed flat down.

(5.) **Curved Polarisation.**—I have defined "polarisation of light" as being a vibration in a single plane. But the term is used more comprehensively, so as to include vibrations of a *spiral* kind. I hold a small weight suspended by a string, and set it in motion to and fro like a pendulum. It vibrates in one plane only. Let this be north and south. If, at the moment the weight is at the end of one vibration, and about to commence another, I tap it lightly, so as to move it also in an east and west direction, it has now two distinct forces acting upon it, one tending to move it N. and S., and one tending to move it E. and W. The result is, theoretically, a quadrangular motion — practically, a circular. Its motion is N. E., then S. E., then S. W., then N. W. The figure thus described is in theory a diamond; but in practice it becomes a circle or an ellipse.

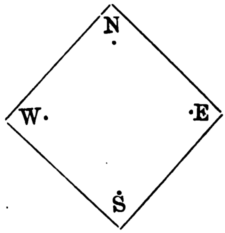


Fig. 196.

Thus let the polarised vibration be from W. to E. and a force acting from S. to N. be added. These two forces will combine to produce a motion from W. to N., from N. to E., from E. to S., and from S. to W.

If the amount of motion from W. to E. exactly equal that from N. to. S., then the movement will be circular. If either be greater than the other, the motion will be elliptical—*i. e.*, one diameter will be greater than the other. If one of the diameters gradually decreases until it becomes 0, then the elliptical polarisation becomes plane.

If, then, a plane vibration receive any impetus in a second plane, the result will be a curved motion. But how can a vibration receive an impetus? It is not *matter* but *motion*. Truly; but motion is the motion of matter, not motion abstracted from matter.

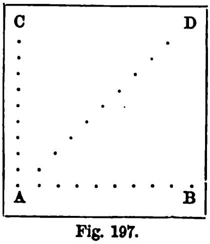


Fig. 197.

Let there be a vibration to and fro between A and B. This will pass from particle to particle, each moving but a short distance to and fro. When the particle A is moving, and all the

others are at rest, let a force be applied that, by itself, would tend to set A in motion towards C, and so to set up a vibration in the particles between A and C. A can no longer move directly towards B, because of the new force; nor can it move directly towards C, because of the old force. The result will be its motion towards D, and the setting up of a vibration in the atoms of the line A D, while the atoms in A B and in A C remain at rest. Thus the direction of a vibration is changed from A B to A D; and this is what is meant by saying that a vibration receives a new impetus.

It will be well to bear in mind that the second force need not be at right angles to the first, nor need it act at any particular point in the range of the vibration.

(6.) **Methods of producing curved Polarisation.**—The question now occurs, How can this second impetus be given to a ray of polarised light? One method is by the convergence of two plane polarised rays. Two such rays may meet at any angle and with any inclination of their planes. If I use the two flat tin tubes already spoken of (p. 322) to represent the two rays of light, I may place them together at any angle, and side to side, edge to edge, or the edge of one to the side of the other, &c. Also the two rays may have any given ratio of intensity.

If their planes are the same, the resulting ray will still be plane polarised; but if the planes be at right angles, and the rays be equal, the result will be circular polarisation.

If the rays be unequal, or if the angle be less than 90°, the resulting ray will be elliptically polarised. It will be seen that the laws governing these are the ordinary laws of mechanics, and that the results are examples, in a very refined degree, of these ordinary laws.

Another method is the use of transparent substances. A ray of plane light passing through a crystal may be elliptically or circularly polarised by means of a motion conferred, not by a second ray of light, but by the crystal itself. I have described these under the head of "Apparatus," at the end of this section of the book.

(7.) **Colours from interference of Polarised Light.**—Colour depends on the velocity and extent of the motion given to the optic nerve by the light falling on it. Now two ordinary rays of light meeting produce colour; so will two rays of polarised light, under similar circumstances. If a ray of light fall on a lens of selenite, or any other doubly-refracting crystal, it will be divided into two rays at right angles to each other. By proper apparatus these two rays may be made to meet, and by their mutual interference produce coloured figures.

A distinction may be drawn between the colours of Newton's *rings*, which are caused by the interference of two rays of ordinary

light, and the coloured figures of polarised light, caused by the interference of two rays of polarised light. But the distinction will prove, I think, to be more in name than in fact.

To save repetition I have described the method of producing these coloured images under the head of "Apparatus for polarisation" (p. 328).

(8.) **Nature of Polarisation.**—We say a magnet is polarised when all its constituent particles are arranged regularly side by side, all having the N. poles turned one way and the S. poles the other. We do not pretend to explain what we mean by N. and S. poles, but only to say that the body magnetised has each particle arranged in obedience to some power exercised over it by the body of the earth. This power may be inherent in the earth, or conferred on it by its revolution or motion in its orbit; and arrangement of the particles may depend upon the shape, or weight, or nature of the particles themselves: all that is meant is, that the earth *does* exert force, and that the particular body has its atoms subjected to this force. The term "polarised" is given to any body whose particles are so arranged.

In the same way we mean, by the term "polarised light," a ray of light whose direction of vibration is in one plane, in obedience to some force to which it has been subjected. This plane need not have any reference to the earth's geographic or magnetic poles, but it has reference to the position of the refracting and reflecting body by which the polarisation is produced. This is saying no more than that the same force that polarises the light also determines the plane of polarisation.

Magnetisation is a polarisation or arrangement of *matter;* polarisation of light is an arrangement of the *motion* of matter in a state of vibration. By matter in a state of vibration I mean a body that does not move as a whole, but whose particles are constantly moving through very minute intervals of space, just as a pendulum moves to and fro, but does not change its position beyond certain limits, and continually returns to its original place.

Polarisation of light, therefore, means no more than the conversion of an ordinary beam of light, vibrating in all directions in parallel planes, to a ray vibrating in one plane only; or rather it means that the force impressed upon certain reflecting and refracting bodies by ordinary light enables those bodies to set up other forces each acting in one plane only, and having all the other properties of light.

I have used the term polarisation of light because it is so much more easy to describe and to understand, but polarisation of heat is effected by similar apparatus. The experiments, results, and laws of both seem to be the same. Very possibly, if we had suitable apparatus, sound would prove as amenable to the same set of influences as heat or light.

(9.) **Apparatus for Polarisation.**—*To polarise by Reflection.*—All that is essential to produce polarisation by means of reflection is a ray of light and a piece of glass. If the ray of light fall on the glass at any angle, the reflected ray will be more or less polarised; if the angle be about 55° with the perpendicular, or 35° with the surface, the reflected ray will be wholly polarised.

To polarise by Refraction.—Single Refraction.—The reflected ray just mentioned is not the only ray produced by the incident ray; there is also a refracted ray (the glass is not silvered) which is partially polarised. By partially polarised I mean that part of the ray is polarised. We have the ordinary phenomenon of a ray of light falling on a piece of glass, and being partially reflected and partially refracted. Usually the greater part of the incident ray is refracted, a small part only being reflected. *The quantity of the refracted ray that is polarised is considered to be always equal to the quantity of the reflected ray that is polarised.* Suppose $\frac{1}{4}$ of the whole to be reflected and polarised, then $\frac{3}{4}$ is refracted, and $\frac{1}{3}$ of this, $\frac{1}{4}$ of the whole, is also polarised. This leaves $\frac{1}{2}$ as being refracted without polarisation.

We have now to consider if there be any way by which we may polarise the whole of the refracted ray. By placing a second plate of glass behind the first, we have a second reflection and refraction, the reflected ray being again $\frac{1}{4}$ and the refracted ray $\frac{3}{4}$ of the whole portion remaining unpolarised. By a third plate being placed behind the second, we get a third reflection and refraction, and we may increase the number of plates until the whole of the remaining portion of the ray is polarised.

To recapitulate, and, for simplicity, keeping the *assumed* ratios of $\frac{1}{4}$ reflected and $\frac{3}{4}$ refracted at each glass plate, we have—

1st plate, . . .	$\frac{1}{4}$	reflected, polarised.	At each fresh surface the half of the light remaining unpolarised is transmitted still unpolarised, one quarter reflected and the remaining quarter refracted, both polarised.
	$\frac{1}{4}$	refracted, polarised.	
	$\frac{1}{2}$	refracted, unpolarised.	
2d plate,	$\frac{1}{4}$ of $\frac{1}{2} = \frac{1}{8}$	reflected, polarised.	
	$\frac{1}{4}$ of $\frac{1}{2} = \frac{1}{8}$	refracted, polarised.	
	$\frac{1}{2}$ of $\frac{1}{2} = \frac{1}{4}$	refracted, unpolarised.	
3d plate,	$\frac{1}{4}$ of $\frac{1}{4} = \frac{1}{16}$	reflected, polarised.	
	$\frac{1}{4}$ of $\frac{1}{4} = \frac{1}{16}$	refracted, polarised.	
	$\frac{1}{2}$ of $\frac{1}{4} = \frac{1}{8}$	refracted, unpolarised.	
4th plate,	$\frac{1}{4}$ of $\frac{1}{8} = \frac{1}{32}$	reflected, polarised.	
	$\frac{1}{4}$ of $\frac{1}{8} = \frac{1}{32}$	refracted, polarised.	
	$\frac{1}{2}$ of $\frac{1}{8} = \frac{1}{16}$	refracted, unpolarised.	

And so on, about twelve plates producing practically perfect polarisation. There is probably, also, a second division at the second surface of each plate.

Double Refraction.—We have seen that some crystals (for example, Iceland-spar) divide a ray of light into two—or rather, that a ray of light falling on such a crystal produces two rays. Both of these are polarised, and both are parallel to the original ray. Thus the ray O, falling on one side of the piece of spar, produces two rays on the other side, one at C and the other at D.

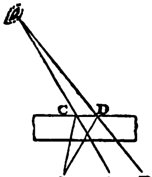


Fig. 198.

On emergence, each of these is parallel to the original direction, obeying the same law. Thus the incident ray A o, fig. 199, falling on one side, emerges on the other as o' B, parallel to A o. But in double refraction there are *two* emergent rays, *both* parallel to the incident ray, and *both* polarised.

The problem is, how to separate these so as to get a single ray of polarised light. This might be done by using a prism instead of a plate. This would make the rays divergent, and so the two rays would be more separated at every increase of distance. But also the light would be decomposed or coloured. To avoid this, and to obtain a single ray of polarised light, a Nicol's prism is one of the best instruments. It ingeniously interposes an obstacle in the very centre of the prism, which turns aside one ray, but which the other ray overcomes—just as an ordinary shield or breastplate might divert a bullet and be pierced by a cannon-ball. A piece of spar, having parallel sides, fig. 200, is cut diagonally, and then put together again by means of a thin layer of cement. The object of the cutting is not to divide the spar, but to interpose the layer of cement. The ordinary ray is totally reflected—*i. e.*, turned sideways—by this layer (which is for this purpose composed of Canada balsam); while the extraordinary ray passes through it, and emerges alone.

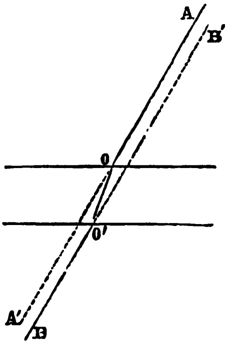


Fig. 199.

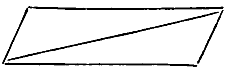


Fig. 200.

The refractive power of Canada balsam is greater than required to divert the one, but is not sufficient to divert the other. The action of the prism is essentially the interposition of this obstacle within the prism.

But why should the two rays have differing forces? Why should one only be able to pass through? This might be answered by referring to polarisation by reflection (p. 322), and asking why a ray of polarised light will be almost wholly reflected or

wholly transmitted according as it is vibrating parallel to the plane or at right angles to it—according as it impinges sideways or endways on the surface? The two rays passing through the prism and meeting the cement are also vibrating in different planes, one falling side and the other end ways upon it, and so one exerts more force than the other.

(10.) **Circular Polarisation.**—I have already shown that elliptic and circular polarisation is produced by the interposition of two rays of plane polarised light. The problem to be solved is to get two such rays. "Fresnel's rhomb" is the usual instrument. It is a piece of glass with parallel sides, two of its angles being 126°, and the other two being 54°. If such a plate of glass be placed at an angle to the plane of a ray of polarised light falling on it, it will be totally reflected twice. The result of the first reflection will be two rays, both polarised, at right angles to each other, and both coincident. The result of the second reflection will be the combination of these two rays into a single ray of polarised light. If the angle of the plate and the plane of the original ray be 45°, the resulting compounded ray will be *circularly* polarised; if it be more or less than 45°, the result will be a ray *elliptically* polarised.

(11.) **Test of Polarisation.**—How shall we prove whether a given ray of light be polarised? It does not produce any special and easily observable effect under ordinary circumstances. One test is to place in the path of the ray to be tested a substance having a cleavage—that is, a substance made up of laminæ or plates. It is found that if such a crystal be interposed in the path of a ray of polarised light, it will sometimes allow the ray to pass through, and sometimes prevent the passage.

To post a letter in a letter-box it is necessary that it be parallel with the length of the opening. If placed across the opening it would be stopped by the sides. So a ray of polarised light—*i. e.*, a ray of light vibrating in one plane only—will only pass through the crystal when the axis of the crystal is parallel with the vibration of the ray. If the crystal be gradually turned round, the light that passes will gradually diminish until, when the axis is at right angles to the plane of vibration, it is wholly prevented from passing.

These crystals, or any substance of which the molecular arrangement varies in density, have the power of polarising light, and also of testing this polarity. Therefore, two pieces of tourmaline, for example, put in two frames, and united by a handle (something like a pair of sugar-tongs, the crystals being at the extremities) will serve as a *polariser* and *analyser*—the one plate causing the polarisation, and the other proving its existence.

Thus the first plate resolves an ordinary ray of light into rays at right angles to each other. Both of these rays may fall on the

second plate, but only the one parallel to the axis of the crystal will pass through, the other being stopped.

A better method is by the use of Iceland-spar as a polariser, and a Nicol's prism as an analyser. Here, as before, the spar produces two rays of light vibrating at right angles to each other. One only of these rays is transmitted by the Nicol's prism, and this only when the axis of the prism is parallel with the vibration. If it be placed crosswise, no light at all passes.

Let us suppose the two crystals thus placed crosswise, and no light whatever to pass through, I now interpose between them a third crystal (say, a plate of selenite). I put this obliquely—*i.e.*, parallel to neither of the other crystals—and light is now transmitted through the three crystals. The plane of vibration of the interposed crystal acts as a kind of inclined plane to lead the light from one crystal to the other, bridging the interval it cannot leap.

If the interposed crystal be thick the light will be white; if thin it will be coloured; and the colour will depend on the thickness of the plate, and vary if that thickness vary.

If the interposed crystal be in the shape of a prism, we shall get refraction, and a kind of spectrum. But if instead of a prism I use a double concave plate of crystal, I get instead of bands of coloured light a series of concentric coloured rings.

SUMMARY.

(1.) One ray of light may be divided into two or more rays, both by reflection and by refraction; and these rays are more or less polarised—*i.e.*, vibrate in one plane only. Page 321.

(2.) A ray of light passing through a transparent body of unequal density, is divided into two refracted rays, each vibrating in one plane only. These differ between themselves by vibrating in planes at right angles. Page 322.

(3.) A ray of light falling on glass at an angle of nearly 56° with the perpendicular to the surface, or 34° 5′ with the surface, is partially reflected and partially refracted. The reflected ray is wholly polarised, the refracted ray only partially, but the *quantities* of light polarised are equal. Page 323.

(4.) If a polarised ray of reflected light fall upon a second mirror parallel to the first it is almost wholly reflected: if it fall upon a mirror perpendicular to the first, it is wholly transmitted. Page 324.

(5.) Plane polarised light is only one example of polarisation. A ray of light may be polarised so as to vibrate in a curve, either a circle or an ellipse. Page 325.

(6.) A ray of curved polarised light is produced by the meeting of two rays of plane polarised light. Page 326.

(7.) Colours, and bands of light and shade, may be produced by the interference of polarised light. Page 326.

(8.) The term polarisation is borrowed from the idea of a magnet—the ray of light being supposed to have poles, or sides, of vibration. Page 327.

(9.) The apparatus requisite for polarisation consists of a reflecting or refracting substance—glass, Iceland-spar, tourmaline, and selenite, are substances usually employed. "Nicol's prism" is an instrument for plane polarisation. Page 328.

(10.) For circular or elliptical polarisation "Fresnel's rhomb" is the ordinary instrument. Page 330.

(11.) The test of polarisation is in the fact that a ray of polarised light can pass through a crystal only when the axis of the crystal and the plane of polarisation are parallel. Page 330.

CONDUCTION.

(1.) **Introduction.**—We speak of a *conductor* as a person who leads or guides us; of a *conduit* as a channel for the passage of water; so we call a substance a conductor if it conducts or permits the passage of force, either as heat, sound, or electricity. Thus we say that iron is a good conductor because heat travels rapidly along it, as is shown by a poker placed in a fire, when the handle also soon becomes heated. We say that glass is a bad conductor, because we can hold a piece of glass in a flame and not feel any heat even within a few inches of the flame. It might be considered that air, through which heat and light travel so easily and completely, is one of the best conductors, but it is doubted by some whether it be any conductor at all.

(2.) **Effects of Conduction.**—The effect of conduction is the transfer of force. Just as by means of a pipe I can transfer water from one vessel to another, so by means of a poker I can transfer heat from a fire to a pail of water, sound from a kettle to the ear, or electricity from one body charged with it to another less so. A thin wire stretching from one town to another, hundreds or even thousands of miles apart, will conduct electric force from a battery to a needle or bar of soft iron.

It may be asked, What is the effect of the conduction upon the conducting body itself? What would be the effect, upon a pipe, of water passing through it? One effect would be that the pipe would itself contain some of the water, that every portion of the transferred water would pass through every part of the pipe. So a conductor of heat is itself raised in temperature by the passage of heat through it.

The effects of conduction may therefore be said to be two:—(1) the transfer of force (in whatever form) from one extremity of the conductor to the other; and (2) the absorption of some portion of the force by the conducting body. But air allows sound, heat, light, &c., to pass through it completely, or almost so; and it is therefore considered that the ether, whose vibrations are con-

sidered to be light and heat, passes through air, between its particles, and without in any way affecting it. Also, a piece of metal, or other good conductor, transfers heat in all directions, though not with equal readiness, while it passes through air only in straight lines. Thus a circular plate of metal, if heated at one point, would give off heat at every point on its circumference, while the same heat that thus passes in all directions through the *metal* would only radiate through *air* in one direction.

From these two facts, heat is said to *radiate* through air and to be *conducted* through metals. This implies that conduction is not only transmission of force, but also being affected by it. But conversely we say that glass and sealing-wax are *bad* conductors, because they absorb so much of the force and transmit so little. We may hold a short piece of sealing-wax even when one end is burning. Therefore transmission of force is the one essential condition and effect of conduction, though, when this is most complete, it is called radiation.

(3.) **Varieties of Conduction.**—Heat, sound, electricity, and galvanism may be conducted; but we cannot transmit light or magnetism in the same way. Nor can we transmit heat, sound, and electricity in exactly the same degree by exactly the same medium. Thus a fine wire will conduct electric or galvanic force, but heat and sound require a thicker conductor for their rapid transmission. This probably follows from the difference between the two kinds of force, heat and sound being vibrations, while electricity is probably a force of arrangement rather than of vibration. But this is only a difference of degree, for a charge of electricity that will be conducted by a thick wire will be converted into heat if it be communicated to a thinner wire, and this so much as to fuse the wire.

We may therefore say that force is conducted in one of two ways; by vibration, communicated from particle to particle, as in heat or sound; by polarisation, also communicated from particle to particle, as in electricity and galvanism. Either of these methods readily passes into the other.

(4.) **Conducting Substances.**—*Solids.*—Of solids, metals are the best conductors; other inorganic substances, such as earth of various kinds (clay, sand, marble, &c.), have much less conducting power. Organic substances (such as wood, straw, cotton, &c.) are still worse conductors.

Liquids.—Conductivity in liquids is usually much less than in solids. Thus water may be boiled in a glass vessel over a lump of ice without the ice being melted, the heat finding it easier to boil the upper stratum of water, than to pass downwards through the water and glass to the ice: a kettle of water placed in front of a fire, or below it, so that the heat has to pass *sideways* or *downwards*, is very much longer in reaching the boiling-point

than when placed above the fire. In the first two cases the heat is transmitted by conduction only, and that very slowly; in the latter, the motion upwards of the heated particles comes into action and produces the effect much more readily.

Gases.—As I have already said, it is a question whether gases have a conductive power at all. That heat passes through gases is beyond a doubt, but whether by conduction or convection is disputed. In any case, it may safely be considered that, bulk for bulk, the conducting power of a gas is very small indeed as compared with that of solids, especially metals.

In furs, the intervals between the hairs are filled with air; and these are so separated that convection cannot well take place. The result is that furs are very bad conductors. A cat will lie inside a fender, exposed to a scorching heat, without appearing to be otherwise than comfortable.

(5.) **Causes affecting Conducting Power.**—The same substance has not always the same degree of conducting power. This is affected by various circumstances.

Temperature.—A cold piece of metal will conduct heat better than a warm piece; also, therefore, the same piece of any conducting substance will decrease in conductivity as its temperature is raised. Conductivity therefore decreases as the temperature increases, and increases as the temperature decreases; or, in other words, conductivity varies inversely with the temperature. A moment's reflection will show this to be what might be expected. The more closely the atoms of a body are together, the more promptly will any force communicated to one be delivered to the next. A row of marbles are placed closed together, I strike the first, almost all the force acts upon the last, which is the only one to be moved to any extent. The same marbles are placed at short intervals; a force communicated to the first now moves each one through one of these intervening spaces, and the last is moved by only what remains of the original force. The greater these intervals the less force remains to act on the last. So the more distant the particles of a body, the less will any vibration given to one reach the next; heat separates the particles of a body, and therefore leaves more work to be done in crossing the intervals. Or, in electricity, the force of arrangement will be less as the intervals through which atoms act on the next is increased.

Molecular arrangement.—Wood has what is called a "grain," minerals have "cleavage," crystals "axes of crystallisation." In other words, wood is composed of threads or fibres, minerals of plates or leaves, and crystals of groups. These arrangements affect the passage of heat or electricity, and the modification may, as before, be traced to the differences of distance at which the atoms act on each other. If we were considering the mutual action of two bar-magnets we should take into account the distance between them, and should find the action increase as

the distance was decreased, and *vice versa*. Just as really does the distance between two molecules of a body (however small these may be) affect their action on each other, whether that be one of vibration or of arrangement. The laws of nature know nothing of large or small; an interval of one-millionth of an inch is as real an interval as one of a mile. It is only the weakness of our perceptive powers that makes us think otherwise. If, therefore, I use wood as a conductor of heat, I find that its conductivity is greater along the fibre than across it; if I use a mineral, I find heat to travel along a plate or leaf more readily than across the plates, from one to another; if I use crystals, I find the most ready passage to be along the axis, and the least across it.

We must distinguish between mere weight and compactness. It might reasonably be expected that the heaviest woods or metals would be the best conductors, because of the greater number of atoms in any given volume, and the consequent greater density. But it does not follow that all atoms of all woods or metals are exactly the same size, and that weight represents simply the number of atoms present. It may rather be that conductivity depends upon the number of intervals and their extent. The larger the atoms of any given substance the fewer the intervals, and possibly the larger, since small atoms would fit together more compactly than large ones.

(6.) **Connection between Specific Heat and Conductivity.**—If I were to draw off water from a cistern by two pipes of equal bores into two pails, also of equal sizes, but one having several holes in the bottom, these two pails would not be filled at equal rates. The one having holes in it would part with a portion of the water received, and so be filled less rapidly than the other.

So if I make three pokers of equal sizes, one of iron, one of copper, one of bismuth, and place them side by side in the same fire, the handles will be found to rise in temperature at different rates. The parts of the pokers in the fire correspond with the pipes spoken of above, and the other parts, heated by conduction from these, correspond with the pails. The rise in temperature of these corresponds with the rise of the water in the pails. The specific heat of iron is $\frac{11}{100}$ of that of water; of copper is $\frac{9}{100}$; of bismuth is only $\frac{3}{100}$. This means that the same amount of heat that will raise a given weight of iron 1° will raise an equal weight of bismuth nearly 4°, and of copper $1\frac{1}{4}$°. So that, considering only the specific heat (or effect of heat upon each poker), the bismuth would rise much more readily than the copper one, and iron one most slowly; but another fact has to be considered.

The pail that had the fewest and smallest holes would fill most quickly, but if the pails were of different sizes, then the depth of water would depend, not only on the amount of waste, but also

on the diameter of the pail. So the conducting power of a body —that is, the rapidity with which heat passes along it—must be taken into account.

Heat travels along copper more rapidly than along bismuth, but also iron absorbs more of the heat that reaches it. A rough parallel may be made thus: construct a metallic pipe of small diameter and a porous earthen pipe of large diameter, and, placing them side by side, feed them with equal quantities of water. The larger bore of the pipe made of earth will represent a better conducting power than that represented by the small bore of the metal pipe. The porosity of the earthen pipe will represent a greater specific capacity than the smooth surface of the metallic pipe, and part of the water will soak through instead of passing out at the other end.

If, now, I construct two pipes of equal lengths and diameters, but one of copper, the other of bismuth, the greater conducting power of the copper will allow of the more rapid transmission of the heat that does pass throughout its length, but the greater capacity for heat of the copper will absorb more of the heat, and so leave less to pass through.

It will depend upon the ratio of the amount lost by inferiority of conducting power to that gained by inferiority of specific capacity, whether the bismuth allows the passage of more or less heat in a given time than the copper.

(7.) **Nature of Conduction.**—Conduction, then, is simply the transfer of force from particle to particle of the body through which it passes. This is usually accompanied by more or less of absorption, but not always so.

Heat and electricity are easily conducted, but light cannot so well be transferred by this means, because of the absorption usually occurring reducing the light to heat. Magnetism, also, cannot so well be conducted, because it is a force definite in amount, and not continuously produced as heat or light. Sound can be conducted, but the comparatively enormous extent of the vibration makes the conduction apparently to differ in some respects. The sound of a piano can be transmitted along a rod for a considerable distance (p. 48).

But conduction can also occur without any perceptible absorption, as is shown in the transmission of heat through ice.

Ice contains, very frequently, small globules of water in its liquid condition, and it was for some time considered that these had not been frozen at all, but enclosed by the ice. Then, when it was noticed that an air-bubble was always present with each globule of water, it was thought that the heat which passed through the ice without melting it had heated the air, and that the air, in turn, had melted the surrounding ice. It was proved by experiment that the water was formed by the melting of ice at the points where it was found; and the question then became,

What could cause heat to pass through one part of the ice and melt another? Considerations of specific heat showed that the air could not be the means of melting the ice near it.

But a moment's reflection as to the exact nature of melting gave a new direction to the thoughts. By melting, or liquefaction, we mean a separation of the particles of the solid. Just as a force acting on the first of a row of marbles close together moves only the last, so heat, acting on the particles of ice, was transferred from particle to particle until it reached the space occupied by an air-speck, where the last atom of ice would be detached, just as the last marble was, through a certain space, because of the less resistance of the air. In this way each successive heat-wave would detach successive particles, and so, by separating these, produce the liquid condition.

It may be asked, How can the presence of these liquid globules be detected? By the refraction of the light passing through, just as a spoon is visible in water.

SUMMARY.

(1.) The passage of force through solids or liquids is called conduction. Page 333.

(2.) The chief effect of conduction is transference of force, but the conducting body is usually more or less affected by the passage. Page 333.

(3.) Heat, sound, electricity, and galvanism may all be conducted. Page 334.

(4.) Solids are the best, and gases the worst conducting substances. Page 334.

(5.) Conductivity is affected by temperature and by molecular arrangement. Page 335.

(6.) Conduction is also affected by the specific capacity for heat of the conductor. Page 336.

(7.) Conduction is the communication of force from particle to particle. Page 337.

CONVECTION.

(1.) **Introduction.**—In a series of experiments on the conducting power of metal, mercury was assigned a high place, being fourth on the list, next to copper; silver being the first, and gold the second. The numbers expressing the ratio found were—

Silver, . .	1000	Then came aluminium, zinc, iron, tin, steel, &c.
Gold, . . .	981	
Copper, . .	845	
Mercury, .	677	

On this report being presented to the Royal Society, Dr Bence Jones suggested that it might be worth while to re-examine the experiments, so far as mercury was considered, with a view to finding whether any exceptional circumstances occurred, owing to the mercury being a liquid, to give it so high a place.

The suggestion was adopted, the experiments were repeated, with the variations suggested by Dr Jones, and the result was the alteration of the number representing the conductivity of mercury from 677 to 54. The variation was the transference of the source of heat from below the mercury to above it. Just as a kettle of water would be much longer before it reached the boiling-point if placed below the fire instead of above it, so the mercury received heat much more slowly when the heat passed downwards through it.

Besides placing the heat above the mercury, it was also placed beside it, the results being the following:—

54,	heat applied above.	
160,	,,	at the upper edge.
216,	,,	at the side, towards the top.
229,	,,	at the side, towards the bottom.
423,	,,	at the lower edge.
679,	,,	below.

The numbers represent the conducting power of mercury as compared with that of silver, which is called 1000. The true

conducting power of mercury is expressed by 54—the higher numbers being accounted for by convection.

(2.) **Cause of Convection.**—Cork floats on water (or rather, water sinks below cork), zinc floats on mercury, water also floats on mercury; because, in each case, the heavier body sinks to the bottom and pushes up the lighter. When a kettle of water is over a fire, the lower particles, becoming heated, become also lighter, and are pushed up by the colder (and therefore heavier) water, which sinks to the bottom. The lighter and hotter water passing through communicates more or less heat in its passage, and so the whole body becomes the sooner heated to any given temperature. The term *convection* is used in the ordinary sense of the word *convey*, each particle moving as it is heated, and *conveying* heat with it. Any liquid and any gas is heated by this method when the heat is applied below; when it is applied above, the upper layer of particles is first heated, and remains at the top, the heat being *conducted* downwards, and much of it being reflected into the air.

(3.) **Examples of Convection.**—A kettle of water and the boiler of a steam-engine are familiar examples. When it is required to heat a liquid for any chemical work, the usual method is to place it in a vessel over a spirit-lamp or gas-flame. The heat of the sun heats the air below it, and this rises, because of its less specific weight when heated, and leaves a vacuum below. This vacuum is filled up by the colder air from the north and south, which rushes towards the torrid zone, and so is the primary cause of our winds, which are complicated by the rotation of the globe, and by many other disturbing causes. These are all examples of convection of heat.

Electricity may be conveyed in the same manner as shown in the to-and-fro motion of pith-balls when an excited rod is held over them. If they be on a table, or any conducting body, they first jump up to the rod and then fall back, then jump again and again fall back, &c. The explanation is that they gradually "convey" the electricity from the rod to the table, just as one might empty a glass of water by means of a spoon. The rod is excited, the table and pith-balls are neutral. The rod attracts them, they jump to it, become charged from the rod, fall to the table, communicate to it their surplus electricity, and become again neutral. In this way they convey the force from the rod to the table.

(4.) **Nature of Convection.**—The heated liquid is said to rise because of its less specific weight, or rather the colder liquid falls because of its greater specific weight. But the question may occur to some, Why should the liquid become lighter because warmer? You may say to me, "If heat were an entity that could, as was thought of old, be forced into bodies, then they

would become heavier instead of lighter. The theory that it is only force, and causes expansion only by means of the vibrating or other motion conferred on each particle, will explain why a solid should become lighter when heated, because the same number of atoms occupy a larger space. But in a liquid, which you define as a collection of independent particles, how can this be the case? If the force be communicated to the lower stratum of particles, either it will be transmitted throughout, as in air, and the water not affected, or else the vibration of the lower particles will push up, bodily, the whole mass of water above it, unless it condense it by forcing the particles above more closely together. How can mere motion or vibration make a *particle* larger, when the extension of a solid is defined as being the pushing apart of the particles, not their increase of size?"

I might reply that, in the case of water, we are dealing with a compound body, and not an elementary substance. Water is composed of oxygen and hydrogen, and therefore the smallest particle of water must have at least two atoms, one of either constituent, and must therefore be considered as much subject to the law of expansion as any other body, however large. In the case of mercury, which is considered to be a chemical element, I cannot so confidently put forth the same plea; but I can suggest that just as the smallest particle of water consists of two constituents, so the atoms of mercury may unite together in groups of two or more atoms, and that the ordinary liquid condition of mercury means only the freedom of these constituent molecules, and not the freedom from each other of its ultimate atoms. But the convection of mercury is much less in extent than that of water. It might also be suggested whether a row of particles in a vibrating state would not rise by means of their vibrations, somewhat as a man might elbow his way through a crowd; only, of course, without the volition that urged the man, the moving force being derived from the heat below.

Whatever be the cause, it is certain that a liquid body does increase in volume with heat: a kettle that is filled with cold water will drip at the spout as it warms, if the lid be tight. Also it is certain that this effect is much assisted by the ordinary phenomena of convection when the heat is applied below. Convection may therefore be defined as the rising of the lower particles of a heated body from the bottom to the top, when the heat is applied below, and the consequent more rapid diffusion of the heat throughout the body. A kettle may be removed from the fire and placed on the bare hand, and it will be often found that the handle is warmer than the bottom, because of the rise of heat from the bottom upwards.

(5.) **Convection of Cold.**—If a liquid be cooled from above, by any means, such as freezing in winter, then the cold particles being smaller might be expected to descend, and so they do. It

might therefore be asked, why does not water freeze at the bottom instead of the top? The reply is, that water decreases in bulk as it is cooled, until it reaches 4° C., and then *if further cooled it expands* until it freezes. So that though a basin of water or a pond might be all cooled down to 4° C., before it began to freeze, yet when it cooled still more, the colder molecules would no longer descend, because of their *expansion by cold*, but would remain on the top, and there freeze.

SUMMARY.

(1.) A liquid heated from below becomes warm much more rapidly than if the heat be applied above. Page 339.

(2.) This is because the lower rows of particles when heated expand, and so rise because of their less specific gravity. Page 340.

(3.) A kettle of water, and the boiler of an engine, are examples of convection of heat. Electricity is also conveyed in like manner. Page 340.

(4.) The expansion of a liquid by heat may be considered to be the expansion of the particles of which it is composed, each of these being considered to be a small solid body consisting of two or more atoms. Page 340.

(5.) Cold is also conveyed from above downwards. The *expansion* of water, as it falls from 4° to 0°, is the cause of water freezing on the top, and not at the bottom. Page 341.

INTER-RELATION OF THE VARIOUS PHASES OF ENERGY.

In the chapter on "Heat" much has been said about heat being a "mode of motion;" about its being obtained by preventing motion, and about its being converted into motion. Similarly, in the discussion of "Light," I have spoken of the probability of light being but a phase of heat, of its conversion into heat, and of its development from heat. Also we have seen how heat can be developed into electricity, and electricity into heat; how magnetism is apparently the constant companion of electricity, and electricity of magnetism. Lastly, even sound is brought into the endless chain of transmutation by the theory that light is but extreme sound.

Now, having discussed the peculiarities of each phase of the question, having learned something of the conditions that produce, accompany, and follow heat, light, sound, electricity, and magnetism, and having become more or less familiar with their coincidences and dissimilarities, we must face more directly the question, How are these various and varying forces related amongst themselves? Does the presence of any one imply the presence of any or all the others? If so, which is the primary? Or are all of them but secondary phases of some other, which is the primal force? If so, what is this primary force?

(1.) *How are these various and varying forces related amongst themselves?* Heat, light, and sound are all believed to be *vibrations*. The questions immediately occur, What is the medium of these vibrations? What are their respective rates of vibrations? their extents of vibration? numbers of vibrations in any given space?

In the case of sound, these vibrations are of comparative slow rate, great extent, and small number. In the case of heat and light, the vibrations are of extreme rapidity, almost infinitesimal minuteness, and in enormous numbers. These three points, rate of

vibration, extent of wave, and number of waves, are closely connected; it will be found that when the waves are of large size, as in sound, their rates and numbers are expressed by small numbers; but that when the waves are very small, as in heat and light, the rates and numbers require for their expression numbers correspondingly large.

These comparisons are shown by the following table:—

	No. of Vibrations per inch.	No. of Vibrations per second.	Extent of wave-length in feet.
SOUND—			
C 	.023	256	4.3
C 	.046	512	2.1
C 	.099	1024	1.1
LIGHT—		Billions.	In ten millionths of an inch.
Red, . . .	39,000	475	255
Orange, . .	41,000	500	240
Yellow, . .	44,000	550	225
Green, . .	47,000	575	210
Blue, . . .	51,000	625	195
Indigo, . .	54,000	650	185
Violet, . .	57,000	700	175

A hasty glance at this table might easily suggest, and even a more mature study would seem to justify, the theory that sound, heat, and light differed only in the rate and extent of vibration; and that we might compare sound to the heavy powerful dray-horse, heat to the light and rapidly-moving hunter, and light to the graceful race-horse outstripping all in speed.

And extended consideration will appear to give further support to this idea of the oneness of sound, heat, and light. All are radiated according to the same law of inverse squares, all are reflected and refracted according to the same laws, all are dispersed, and all may be converged to a point. Adopting, then, provisionally, the notion that heat differs from sound only in that its vibrations are much smaller, and much more numerous and rapid, and from light only in the less number and rapidity but greater extent of these vibrations, it behoves us to inquire what circumstances there

are to prevent our complete acceptance of it; for we must pay even greater respect to the facts that tell against any pet theory than to those that favour it, since the same phenomena may agree with two theories, so that no number of corroborative facts are of much value if one single well-authenticated phenomenon contradicts the theory they seem to support.

The enormous difference between the extent and number of sound waves and heat or light waves seems to separate sound by a large interval from the others; and while we accept the theory that all the phenomena of sound are explicable upon the supposition that ordinary matter, air, water, metals, earth, &c., are the vibratory media, whose motion (resulting chiefly from elasticity) gives to our ears the impulse which we call sound, we are told that for the explanation of the enormous rapidity of such vibrations as give us the sensations of heat and light we require an ether possessing a rarity far beyond that of hydrogen and an elasticity far beyond that of most solids: that no ordinary matter, solid, liquid, or gaseous, possesses the extreme rarity and exceeding elasticity that alone can account for the phenomena of heat and light.

The supposition of this ether, though supported by the opinions of some of the greatest students in this branch of inquiry, is the greatest difficulty in the way of considering sound as a phase of heat and light. The two greatest arguments for its existence are (1) that the exceeding velocity with which light travels demands a rarity and an elasticity beyond those of ordinary matter. (2) The fact that light and heat traverse with the greatest readiness the most complete vacuum that can be produced. In reply to the first, the fact that the ether demands such opposite qualities as extreme rarity and extreme elasticity, is itself a difficulty with some minds in the way of its acceptance; and to the second, that it is by no means certain that a complete vacuum has ever been produced.

A third argument adduced in support of the existence of the ether is the necessity of a medium extending throughout space, otherwise we cannot account for the passage of light and heat from the sun and stars to us on the earth. We are told that ordinary air cannot extend so far, therefore the ether must exist. This theory is scarcely yet a century old, dating from the announcement of the undulatory theory of light, and may be regarded as one of the crutches that were useful, perhaps, in its infancy, but which we may soon expect to see thrown away.

In reply to this, much is adduced to show that an elastic medium, such as our atmosphere would be, and probably is, when free from the attraction of the earth, most probably extends throughout all space.

The attraction of the earth for the atoms of air composing its atmosphere cannot have any practical effect beyond 26,000 miles, for beyond that distance it would be so weakened that it could

not overcome the centrifugal force. Just as an electro-magnet can be made to destroy its own power as quickly as it receives it; so, beyond this distance, the attraction of the earth, when excited upon an atom of air, would (by drawing it into its atmosphere, and so tending to set it revolving round it) endue it with centrifugal force more than sufficient to overcome its own attraction. Thus we may say that the vast space of the solar system might be filled with rarified air without there being any effect by it on the earth, or the reverse. By the same reasoning, we might suppose the great mass of this aerial body to be free from any attraction from the sun. It might be considered to be in simple existence, each atom or molecule being kept apart from the other by the attraction or repulsion of all the surrounding particles.

But the amount of refraction in the case of sunlight is urged against the possibility of such a medium existing throughout the 100 millions of miles between the earth and the sun. The refraction is such as would take place if the atmosphere causing it extended but a very small part of the vast distance through which the light comes. But these two suppositions are not in reality contradictory. Let us assume three things—

1. That the whole space between the sun and the earth is filled with air greatly rarified, each atom, or molecule, existing individually and separate.
2. That only a small portion of this is subject to the attraction of the earth.
3. That this rarified air is the medium of light—*i.e.*, that it is the *ether* of which so much is said.

Then it follows that the refraction of light from the sun would be the effect of its passage through the earth's atmosphere only, and not of its passage through the vast body of air free from the earth's influence.

It is not, I think, too much to say, that the arguments in support of the existence of the ether are gradually losing hold on men's minds, and a corresponding greater reliance is being placed in the simpler and more natural theory, that ordinary matter, such as we are familiarly acquainted with, possesses, under the varying circumstances in which we may easily suppose it to exist, all the qualities requisite for the production of the phenomena of light and heat. It will not, I think, be many years before the "ether" will be referred to as a conjecture of the past, justifiable then, and only then. This I do not say unmindful of the support it has from men far more competent than myself to speak with authority, nor with any pretension to a right to have an opinion of my own, but because the theory seems to be one out of character with the progress that physical inquiry has made during the present century, and because this progress has otherwise uniformly been, and I think will continue to be, in the direction of a simple and natural explanation of phenomena by the action of matter and laws alike familiar. The question, "How are these

varying and various forces related amongst themselves?" is probably answered by saying that, as shown by the table on page 344, they differ only in the number of vibrations, the extent of the wave-length, and the rapidity of vibration; that sound becomes heat and even light if the rate, extent, and number of the vibrations be sufficiently increased; that light becomes heat and even sound if the rate, extent, and number of the vibrations be sufficiently diminished.

(2.) *Does the presence of any one of these imply the presence of any or all of the others?* This is the second question which (as we have seen on p. 343) requires to be answered. The answer follows at once from the preceding paragraph (if that be true): the presence of either light, heat, or sound does *not* imply the *presence* of the others, but *does* imply the power of producing them. A man having a five-pound note (which is only a pledge of credit) can have for it either 5 sovereigns, 100 shillings, 240 pennies, or any combination of these of equal aggregate value. He may change silver for gold, gold for silver, or either of these for copper, or *vice versa*. Just as the credit implied by the note can give gold, silver, or copper, and as any one of these, when possessed, can be exchanged for either of the others; so the power of producing heat implies also the power of producing light or sound in corresponding amounts, subject only to the waste force required to set in operation the necessary apparatus, and also implies the power of converting any one into either of the other two. But light is *not* heat or sound, any more than gold is silver or copper. So that the presence of light, heat, or sound implies *not* the *presence* of the others, but of the power of *exchanging* the one we have for either of the others,—always provided that the conversion does not demand apparatus or skill beyond what we at present possess.

(3.) We come now to a much more important and difficult question, "Which is the primary of these vibrations?" The only answer that can be given is, that no one is primary, but all are derivative. We can convert light into heat, and heat into light, but we have no ground for calling either of these the primary. We cannot so readily convert sound into light or heat, nor produce it from either of these, but we shall see in the next section that we can choose whether we will convert a certain other force into sound or heat. To sum up, we have no reason to justify us in speaking of either sound, heat, or light as the *primary*, but must regard all three as derivative—derived from another force, which is the primitive.

(4.) *What is the primary force from which we can derive all the three that we call sound, heat, and light?* We can convert heat into light, and light into heat, but we cannot produce either from nothing. We must have something else from which to obtain either. What is this other? This may be answered by referring to actual experiment, and producing heat or light by means

of some method other than conversion. Thus to produce heat I employ friction or percussion ; I rub two substances together. I can melt ice by the heat developed by rubbing two pieces together. Whence is this heat derived? Is it a conversion of some other force? We may answer this by analysing our experiment. When I rub the two pieces of ice together, I use muscular force : each is pressed against the other; if either be suddenly withdrawn, the other will follow it, not by attraction, but by the force pressing it from without. *Each piece is prevented from moving by the pressure of the other.* Motion which would occur is prevented, and *motion, when prevented, becomes heat.* Therefore motion can be converted into heat, and this heat into light, for by continued friction of solids that do not melt at low temperatures—for instance, two pieces of dry wood—we may have sparks. So from flint and steel we can get light. From motion, by conversion, we get also sound. I have often noticed the passage of vehicles over a piece of roadway near the Royal Exchange which has recently been paved with some elastic and comparatively smooth material. A cab or omnibus rolls over this very quietly, but the moment it reaches the ordinary stone pavement it receives a perceptible check; motion is prevented, and considerable noise is the result. Clearly, a portion of the motion has been converted into sound. Many other such examples will occur to any thoughtful reader. Knock any two things smartly together, clap your hands, ring a bell, knock at the door, in every case motion is prevented and noise follows.

But, some clear-headed reader may say, if motion prevented becomes heat, light, and sound, how are we to know the conditions of each conversion? Is it heat, light, *and* sound? or heat, light, or sound? That is, does motion prevented become *all* three, or *one* of the three? If all three, in what proportion is each? If only one, what are the conditions that determine which it shall be?

To answer these questions completely is, perhaps, beyond the power of any one; to theorise upon them, to suggest replies, may well be counted presumption in one who, like myself, is far too much occupied with active work to have much leisure for the enjoyment of experimental investigation. Still, however presumptuous it may seem—and no one is more mindful of this than myself—I have ventured to put into words thoughts that have taken years to reach their present form, and which have been suggested, not by any vain desire to account for the wonders of natural science, but by a perusal, careful and systematic, but very imperfect, of the history of scientific discovery.

The chief reason I have for believing that they are worth anything, is not a vain confidence in my own powers, nor the faintest touch of disrespect to accepted theories, but the feeling that the ideas suggested by a study of the records of past discoveries in their chronological order are likely to be in keeping with the

spirit of that record, and to suggest the direction of future successful research.

It is admitted that sound may be conveyed from place to place by means of ordinary substances, such as we are familiarly acquainted with, that no assumption of any ether or quality, other than we are accustomed to consider and estimate in ordinary mechanical calculations, is necessary for the explanation of acoustical effects. A blow is given to a table, a stone, the earth, anything that is more or less capable of motion. Two results follow—motion and sound. If the stone, for instance, be resting on a hard rock, the result is more noise, less motion. If it be resting on soft earth, so that it sinks when struck, the result is less noise, more motion. So that we may say, force that tends to produce motion, and is prevented from doing so, becomes noise.

But, we may now ask, what is noise itself other than motion? What is really the difference between noise and motion? I think the answer will be that there is really no difference whatever between the two; that when motion reaches the ear it is noise, because it affects the auditory nerve. Outside the ear it is motion; inside the ear it is motion and sound.

The chief point to which I want to draw attention is this: that it is incorrect though convenient to say that motion is *converted* into sound, because, really, sound is not an extinction of the motion. The motion continues afterwards. I move the handle of a door-bell; this moves the wire; the wire moves the spring; the spring, retracting itself, shakes the bell; the bell, being so moved, is struck by the clapper; the motion of the bell, when so struck, moves the air; the air impinges upon the ear, and sets in motion its various parts; this motion passes from the ear to the auditory nerve; this motion of the nerve is sound. So that **sound is motion**: the converse, that **motion is sound**, is true only when the motion is that of the auditory nerve.

But the motion does not cease when it has become sound. The ear, besides being the medium of sound, is also ordinary matter, and obeys ordinary laws. Motion when communicated to it is as endless as when communicated to anything else. When with a sovereign I buy a book, I might say I had "converted" the sovereign into the book. This would be true, practically, as far as I was concerned, but would not be true of the sovereign, which would exist as truly afterwards as before. So with sound, it is not the conversion of motion, but the result of its presence.

It being admitted that the motion of ordinary matter produces sound, and its continuous vibration (which is motion to and fro) produces continuous sound, what are the conditions of the transmission of this motion, and what modifications are necessary to produce the phenomena of conduction, reflection, and refraction?

I think it will be found that the conditions requisite for these

various results are identical with those required for ordinary mechanical results. To transmit motion from one place to another requires a continuous and connected medium; its reflection requires elasticity and the action of the law known as the "parallelogram of forces;" its refraction may, I think, be explained by the same means. Let A B be the surface of any body upon which a sound-wave falls. (By a sound-wave I mean a motion of such an extent as falling upon the ear would produce sound.) If $a\ o$ be its direction of incidence, $o\ b$ will be its reflected direction. This is the same of a sound-wave as of a ball thrown against a wall—in fact, is an example.

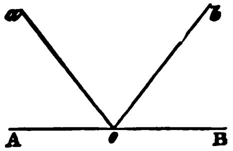


Fig. 201.

A sound-wave means the transmission of motion through the air (if air be the medium) from particle to particle in a straight line. Let $a\ b\ c\ d$ be the successive particles, and let d be the last of them. Then when the sound-wave impinges upon the surface A B it means that the last atom d is impelled against A B, precisely as a ball is thrown against a wall. One is as real a concussion or collision of matter as the other. The ball would either enter the wall or rebound from it, according as the force of impact were sufficient or insufficient to penetrate it. If it rebound, the new line of direction is $o\ b$, the angle $b\ o$ B being equal to the angle $a\ o$ A. There is really no difference whatever between the impact of a ball and of a sound-wave, excepting the difference of degree; and the differ-

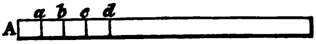


Fig. 202.

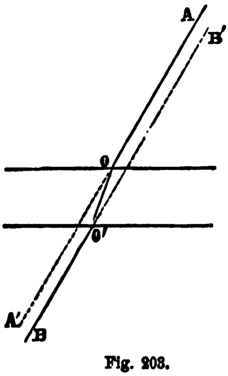


Fig. 203.

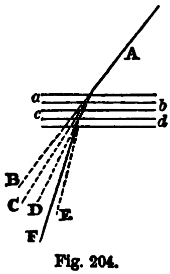


Fig. 204.

ence that in one case the same body, the ball, is moved continuously, while in the other, the sound-wave, each particle is moved

through only a small space. But the change of direction from $a\,o$ to $o\,b$ depends entirely upon the result of the impact of the last atom of air upon the surface of A B. The phrase, when reflected motion follows the same laws as matter, is so far misleading that it suggests a difference in kind. It is nearer the truth to say that reflected motion is an example (in a refined degree) of reflected matter.

In the same way, the refraction of sound may, I think, be accounted for. In the case of reflection the elasticity of the wall is greater than the force of impact, and the ball rebounds; in the case of refraction, the force of impact is greater than the resistance, and the ball penetrates. The change in direction from A o to $o\,o'$, on entering the denser medium, and the change from $o\,o'$ to o' B′, parallel to A A′, can both be explained by the law of "the parallelogram of forces."

So may the continued refraction shown in fig. 204, where the line of force changes from A B to C D E and F respectively on passing through the successive strata $a\,b\,c\,d$.

I think most of the phenomena described in the preceding chapters may be explained by the action of ordinary substances, according

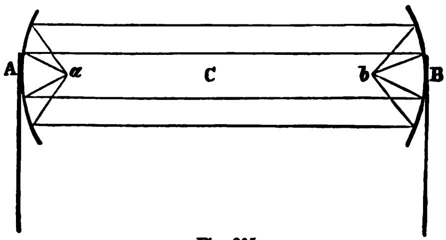


Fig. 205.

to the laws of mechanical action; that they are indeed examples, of a refined character, of these laws. That this is true of sound is already accepted. Thus in the reflection of sound (fig. 205), the movement of a bell-clapper at a sets the air in motion towards A, and the particular particle of air that strikes the reflector is thrown back towards B, and so sets up another line of motion; again, the particular particle of air that strikes on B is thrown towards b. So that the action of ordinary mechanical laws, air being the propelled body, is sufficient to explain the reflection, a translation of sound from a to b.

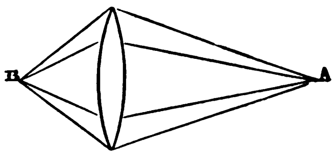


Fig. 206.

In the case of refraction of sound (fig. 206), the air is set in motion in lines radiating from A; and particles of air moving in these lines strike

upon the balloon, or gaseous lens, setting the particles of the gas in motion according to the laws that would govern the action of marbles, or any other solid objects, in similar positions. It must be borne in mind that the particles of a gas, however invisible and mobile they may be, are as *solid* as any object can be. It is only their exceeding small size that prevents us realising this at all times. The motion of the gaseous particles in the balloon acts on the air-particles between it and B, and the ordinary action of ordinary laws produces a convergence at B.

The varying velocity of sound, according as the medium is varied, is also, I think, easily explicable in this way. The denser the medium, the more work there is to be done, the more matter to be moved, in any given distance, and therefore the slower will be the passage of the moving force, just as it would take a man longer to walk a given distance in water than in air, in sand than in water. But a man's force is in this case put forth continually, while a sound is the result of *one* application of force. A man moves his body by taking a step, and it would seem as if he had done no more by the expenditure of his energy. But he has done more: the force which moved his body one step will no more cease than any other force. He has set the air in motion before him, to make room for him, and drawn it behind, to fill up the empty space before filled by his body: he has compressed the earth in one place by the pressure of his foot, thereby generating heat; and has relieved it from pressure in another place, thereby generating cold. It is no reply to smile at the infinitesimally small extent of pressure effected by a lady's foot on a stone pavement. The heat generated on a line of rails, and the wind set in motion, by an express train, are only extreme cases of the same forces as, and are no more real than, the effects of the same *kind* produced by the toddling on the floor of the tiniest infant.

This being admitted in the case of sound, why may not we at once adopt the same explanation for heat and light? Because we must bear in mind that we are still but groping in the dark after truth; that our object is, not to make pretty theories, and to try to understand all phenomena by the observation of a few, but to observe all, and to deduce not theories but general laws. Still it would be as absurd to disregard all analogy in working out our results as it would be to overrate it.

I have already discussed the obstacles in the way of accepting ordinary matter as the medium of heat and light (p. 105). They are chiefly these:—(1) that sound will not pass across a vacuum, and heat and light will; and (2) that the velocity of light appears to require a density infinitely less than that of a gas, and an elasticity infinitely greater than that of a solid.

Assuming, then, that we have a similarity in the phenomena and natures of light, heat, and sound, we come to the question,

What is the relation between these phases of force and electricity?

I have already (p. 105) suggested that the ordinary phases of force may be grouped thus—

Heat Light Actinism	*Force of Vibration.*	Electricity Galvanism Magnetism	*Force of Arrangement.*

The connecting limits between these groups are numerous: in thermo-electricity and the electric light the inter-relation is especially manifest. In each of these cases we require a complete circuit of conducting matter for the production of light from electricity, or of electricity from light.

This may serve as an illustration of the more striking difference between heat and electricity. The one may be sent along a wire, or any conducting substance, but the other requires a complete circuit. Heat can be sent from any one point to any other, but electricity can only travel in a circle, using the word somewhat freely, and not exactly in its geometrical sense. But what could result from the opposition of two unequal currents of heat that could not be produced by a single current? It cannot be any particular temperature, nor any specific amount of heat, since these could be produced at will by ordinary means; nor is it easy to conceive that two opposing, unequal, but similar forces can produce a third force of an altogether different character. Is it not, therefore, probably to the fact of two similar forces acting in opposite directions, though not necessarily in opposition, that we must look for the difference between heat and electricity, a difference not of kind, nor of degree, but of arrangement?

Assuming heat to be a vibration—*i. e.*, that the passage of heat along a wire means that its particles are set in vibration—what is likely to occur when two such forces act at the same time, and from opposite points, on the same set of particles? Might we imagine that the result would be the orderly arrangement of the particles among themselves? Against the idea that electricity is simply heat is the fact that an electric current passes through a copper wire at once, before an ordinary current of heat could pass through the same length, and without developing any signs of heat. Again, an ordinary galvanic current passes at once through hundreds, even thousands of miles of wire forming part of a circuit, the other part of which is the earth; and it is difficult to conceive the current in this case being the result of two unequal heat-currents.

But it is not necessary to conceive all electric currents to owe their existence to the same cause. Just as we consider heat to be a vibration, an actual motion, so electricity may be considered to be a state, or arrangement, of the particles. Assuming it to consist in this orderly arrangement, or polarisation, of the constituent atoms, it is easy to conceive that this may be produced

by more than one means. In thermo-electricity it is clearly a consequence of the application of heat, but in an ordinary galvanic current, produced by a zinc and carbon battery, it is as clearly the result of chemical affinity. It by no means follows that heat and chemical affinity may not be two phases of some more general force, so that all electricity may be alike in character; but it is clear that, by means of heat, and also by means of chemical affinity, we can obtain electric currents (or effects to which that name is given) alike in character and effects. Also we know that chemical compounds are decomposed by the force of a galvanic current through the polarisation of the constituent particles. Is it not therefore probable that the same effect is produced on the atoms of the wire through which the current is said to pass?—that this polarisation, or orderly arrangement of the particles, is the "current"?—and that the same effect may be produced upon a wire through which two currents of heat pass in opposite directions?

It is sometimes said that heat can be derived from electricity that is prevented from pursuing its natural course; and that electricity can in like manner be derived from resisted heat. Thus we know that any badly-conducting substance interposed in a galvanic circuit so as to impede the passage is at once heated (and in extreme cases even melted), while it is said that thermo-electricity owes its existence to the resistance to heat interposed by a compound of two bodies having different conducting powers. This, when briefly expressed, means that heat is accumulated electricity, and that electricity is accumulated heat. This theory, pushed to its logical consequences, might be found not very prolific in scientific data.

But if we consider heat and electricity as two phases of a more general force, as being correlative rather than consequential, may we not say that heat may be converted by resistance into electricity, and also electricity by resistance into heat? Assume heat to be a vibration, and electricity to be an arrangement or polarisation of the atoms of a body, then it is easy to imagine that the force that sets a given body in vibration may, if this vibration be prevented, spend itself in arrangement, and, conversely, a force that begins by arranging may (if this be prevented) expend itself in vibration.

But what is this arrangement? It will be noticed (page 140) that bad conductors of heat are usually also bad conductors of electricity. If heat be a vibration, then that substance which conducts heat badly has its atoms so arranged as to be difficult of vibration. If electricity be an arrangement of atoms, then that body which is a bad conductor of electricity is so because its atoms are difficult of arrangement. When such a body is acted on by heat, probably some portion of the heat is used in arranging the atoms, and so producing a slight current of electricity.

But why should not the same result occur whether the wire be

straight or in a hoop form? It does, for an electric current will be evidenced by the needle if the connection between it and the flame be made only by a single wire, provided some worse conductor be interposed, or even if the wire itself be twisted so as to have its molecular arrangement disordered. But the hoop form produces a much stronger current, probably by reason of the circulation of the force round and round the wire.

So that when we speak of thermo-electricity as being electricity derived from the application of heat, it is probable that our language is more literal than we suppose, and that the electricity is really only the heat under another name. This will naturally suggest, once again, the idea of the changefulness yet indestructibility of force. Just as heat is a "mode of motion," so electricity may be spoken of as a mode of heat, and therefore of motion.

The strength of a galvanic current may be measured by observing the effects produced :—

1. By measuring the amount of chemical decomposition it can effect.
2. By the amount of deflection produced in a magnetic needle.
3. By the amount of heat developed by resistance to the current.

In all cases, however, the results obtained are comparative rather than absolute—*i.e.*, it is much easier to compare the effects of two currents than to discover the absolute strength of either.

Chemical decomposition is a correlative result of a voltaic current. The same current, after decomposing one compound, will break up a second, a third, even a fourth, if its way lies through them. Thus, if I put water in one cup, hydrochloric acid in a second, and sulphate of copper in a third, connecting the liquids by short wires, a current passed through will decompose all the compounds, and all in the same ratio—*i.e.*, the elements will be set free in quantities proportionate to their combining equivalents. The current appears to pass through the compounds, polarising their particles, and to continue its course without having lost much of its power.

We have then to consider **chemical action** as a phase of energy. Is it a force in vibration or a force of arrangement? The answer to this question will be instructive.

By means of heat we can cause combination and decomposition; so we can by frictional and by galvanic electricity. So that force of vibration and force of arrangement are both capable of producing chemical action. Chemical action also can produce both heat and electricity, and must therefore be admitted to rank as one with the other phases of force.

SUMMARY.

All the phases of energy are related to each other. Page 343.

Sound and light differ chiefly in the extent and rapidity of the vibrations producing them. Page 344.

Sound, light, and heat *may* have but one and the same medium. Page 345.

Motion is probably the primary force of which sound, heat, and light are manifestations. Page 348.

The transference of light, heat, &c., are refined examples of the action of ordinary laws of mechanical action. Page 350.

Heat, light, sound, and actinism may be grouped as force in vibration; electricity, galvanism, and magnetism as force of arrangement. Page 353.

Thermo-electricity and the electric light are instances of the transfer of force from one group to the other. Page 353.

These two groups are correlative rather than consequential. Page 354.

Chemical action also is a phase of force, and may be considered as intermediate between the two groups. Page 355.

PRACTICAL APPLICATIONS OF FORCE.

(1.) **Introduction.**—When I want to speak to a man, I move my tongue, and so set the air in motion: the air in his ear is thus also set in motion, and by the action of this he is enabled to understand what I want to tell him. It is as real a motion, as real a blow upon his ear, as if I had thrown a stone at him, and the force exists as much after I have used it as it did before. The sound is not the *end* of the motion, but the accompaniment of it. Excess of sound frequently produces headache, as does excess of light, probably because the motion of the nerves is communicated to the brain in greater quantity, and more rapidly, than it can part with it, and it is therefore in a state of undue activity. Rest is usually the best cure for a headache—*i.e.*, cessation of motion as far as possible, giving the brain time to get rid of its already too great amount.

(2.) **Circulation of Force.**—Whence do I derive the power to move my tongue when I speak? From my bodily strength. How is this recruited? By food. Whence the food? From the earth (for animal food is produced by vegetable), but not only. Light and heat are necessary for the growth of food. Whence come these? From the sun: and now for the first time in the circle we get beyond the earth. Whence does the sun obtain the force which we call light and heat, and which it is continuously pouring upon us? This question it is quite out of our power to answer: we usually talk of the sun as the *origin* of force; but it is not impossible to imagine that the force may be more or less returned to the sun from the planets. But this is a point far beyond the province of my book; and I only mention it to enable my readers to realise the circulation of force, from the sun to the earth, to be reproduced by its trees and grass, by these, used as food, to be placed within our power, not to increase or destroy, but to use (or waste) in our every action.

(3.) **Media *of Force*.**—I have a piece of iron to melt; I place

it in the fire, but the heat is insufficient. This means that I cannot accumulate upon the iron a sufficient amount of force, because the supply by the fire is at too small a rate; it radiates too rapidly to allow of a sufficient amount being collected. I use an oxygen and hydrogen blow-pipe, and I can succeed, because I can supply the force at a sufficient rate. It must be realised that *heat* is *force*, just as really as the blow of a blacksmith's hammer.

I want to melt some ordinary gum, which I can do by water; but I find that hot water will enable me to do this much more readily than cold. Why? Because it contains more force. Whence did the water derive its force? From the fire. And the fire, whence obtained it the force to impart? From the combustion of the coals.

It is often said that force is stored up in coal, derived from the sunlight of past ages. And I once ventured to say to a wealthy farmer of a Yorkshire dale, that coal had been called "the sunlight of former ages, bottled for present use." The worthy farmer replied, that I, being a teacher, "ought to know better than to talk such nonsense." I honour him for his frankness, and am not quite sure that he was totally wrong.

The point which I want to make clear is, that water is much used as a *medium of force*—that by means of it I can *conveniently* move force from one place to another. It is not the only medium, but it is one of the most practically useful.

(4.) **The Steam-Engine.**—This is especially evident in what is called the steam-engine, which some writers now call the "heat engine." I want to move a train of carriages along a railway, and the driving-wheel of the engine seems the most suitable point to which to direct the action of the force I am to use. I might pull the wheel, or push it, or turn the axle. The last is evidently the best method. I attach to the axle a lever, so arranged that a small to-and-fro motion of the other end shall communicate a rotary motion to the axle. How shall I produce this to-and-fro motion? The method in use is to move a piston to and fro in a cylinder, and to connect the piston with the lever. To move the piston *steam* is admitted first on one side and then on the other.

Steam is water of which the particles are urged apart by the force of heat. By cooling it may be reconverted into water. The weight of the train tends to keep the piston stationary; the force in the steam tends to move it. But the steam is enclosed in a metal cylinder, of which the piston is the only yielding part. The force cannot be destroyed, it must either move the piston or escape through the cylinder as heat. The piston is moved, the train also is moved, by the force of the heat in the steam. How was the force communicated to the water? By the burning of so much coal.

(5.) **Combustion.**—Coal burns: so does wood, paper, and in-

numerable other substances. What is *burning?* why does it give out heat? and why is coal the most convenient form of fuel? What we call burning is really chemical combination. If we burn coal, the carbon, which is its chief constituent, unites with the oxygen of the air, and forms carbonic gas. If we burn hydrogen, that also unites with the oxygen, and forms water, sometimes called the "enemy of combustion." The heat is probably derived from the force with which the atoms rush together when uniting. But whence is this derived? Why *do* they rush together and unite? The usual reply is, that they have a chemical affinity for each other; which, translated in plain language, means that they do so because they do so, and we call it "affinity" because we do not know how to explain it. It is often said that because the carbon in wood was derived from the decomposition of carbonic gas, the separation of oxygen and carbon set free the force which causes the reunion when combustion takes place. But the carbonic gas must have been obtained by some previous combination, unless we suppose the oxygen and carbon never previously to have existed separately.

(6.) **Coal as a Medium of Force.**—But why is coal the best form of fuel? A pound of hydrogen in burning will give out more than four times as much heat as a pound of carbon will; a pound of marsh gas will give out nearly twice as much, and a pound of olefiant gas nearly half as much again, as a pound of carbon. Also, a pound of phosphorus will give out nearly as much heat as carbon. Why then use coal so universally?

Because of its practical convenience. Coal is solid, and occupies but small space as compared with gas, to say nothing of the danger of explosion and the trouble of obtaining and conveying the gas. Phosphorus is also a solid, but ignites at a much lower temperature than coal, and is therefore much more dangerous. Coal is compact, easily procurable, does not ignite so easily as to be dangerous, nor with so much difficulty as to be troublesome.

(7.) **Water as a Medium of Force.**—To revert to the steam-engine, the one thing desired is to move the piston to and fro. The force which does this is derived from the combustion of coal; but we cannot light two fires, one each side of the piston, and make them play at ball with it. We require some medium to convey the force from the fire to the cylinder; a manageable medium which can be easily divided into small portions, and sent here or there as we desire. All this water gives us. It absorbs a large amount of force, which it conveys to the cylinder, and it can be divided and directed at will.

(8.) **Electro - plating.**—We saw (p. 183), that a "Daniell's constant battery" derived its element of constancy from the use of a salt of the metal of which the negative plate was made. Thus

the negative plate being copper, a solution of sulphate of copper was used to excite the battery. We saw also that one result was the covering of the copper plate by a deposit of copper. The sulphate of copper was decomposed into its constituents of sulphuric acid, copper, and oxygen. The oxygen was used to replace other atoms of oxygen that combined with the zinc, and the copper was deposited upon the copper negative plate. That is, practically, the oxygen went to the positive pole of the battery, and the copper to the negative.

The chief purpose and advantage of this construction was the constancy of the current. In other batteries the action becomes, after a time, weakened by the coating of the negative plate with the hydrogen derived from the decomposition of water. But in the Daniell battery it is oxide of copper, not water, that is decomposed; and it is copper, not hydrogen, that goes to the negative plate. But this plate being itself copper is unaffected, except in size, by the copper deposited on it.

There were, however, results of another kind, quite unexpected, and which have proved of immense practical importance. It was found that the copper thus deposited was deposited with great regularity, and really formed another copper plate of *uniform thickness* throughout. This second plate could be detached from the first, upon which it was deposited. Upon being so detached it was found that the new plate, from having been built up, atom by atom, formed a mould or casting of the original plate. Wherever this had any slight projection or depression, its place was marked by a corresponding depression or projection.

It was soon seen that this power of obtaining an exact reproduction of a given surface might be utilised for the purpose of obtaining casts of medals, or other small bodies having raised surfaces. But the use of this battery extended beyond the reproduction of a *reversed facsimile* of a surface. The uniform thickness of the deposit made the outer surface of the new plate a second fac-simile, not reversed, of the surface of the original plate; so that the two plates might be left together to form one of greater thickness than the one, but preserving the irregularities of the original surface. This second surface is rough, but can easily be burnished.

The next extension of utility was when it was seen that the two plates need not be of the same metal. In the original battery of Daniell they were both of the same metal, because it was this which gave a continually pure surface of metal, and thus gave the continuous and "constant" action of the battery which is its especial distinction. But this is not necessary when the deposit is the end, and not a means, of the galvanic action.

This power of coating one metal with another and yet preserving its projections and depressions, however fine or intricate, soon suggested the idea of plating metal articles by this means. Its advantages are manifold: especially valuable was the power of

easily regulating the thickness of the deposit and the deposition of an equal thickness on all parts of the surface, so that the depressions were as thickly coated as any other portion. If I place a thin plate of valuable metal over a thicker plate of commoner, and then engrave a pattern on it, I cut away the one plate only, leaving but a very thin substance beneath any deeply-cut part of the pattern ; but by cutting out the pattern on the common metal, and then coating it by making it the negative plate of a battery in which another metal is being decomposed, I get a deposit of this second metal of the same thickness throughout.

In this way teapots, spoons, forks, and numberless other articles of domestic use, are made of a common metal coated with silver, of any degree of thickness, and presenting all the appearance of solid silver. It would be out of place here to describe the methods of this electro-plating otherwise than as they illustrate the principles of electricity.

It is necessary to attach a plate of some conducting substance to the positive as well as the one attached to the negative pole for the purpose of being covered. Why is this necessary? If I connect a wire of copper to each end of a battery, the second ends of these wires become the poles of the battery, and from the positive to the negative pole there passes a continual current of galvanic force. If these poles have termination of unequal size, this force will either diverge from the smaller to the larger, or converge from the larger upon the smaller, according as the positive or negative pole be the larger. In either case the force will be unequal in intensity. Thus, if I suspend a medal to the negative pole, while the positive pole terminates in a point, the current of force will tend to cross the medal in a line between the end of the connecting wire and the point nearest the opposite or positive wire. The deposit will thus be, comparatively, heaped on this line, and decrease in thickness towards the sides. But if I attach to the positive pole a plate of metal of a size corresponding to that of the medal at the negative pole, and bring the two surfaces face to face, within a short distance (say half an inch) of each other, each point of the positive plate will have a corresponding point in the negative plate, and thus the force will be generally and equally diffused over the whole surface.

Another point, of theoretic as well as practical importance, is that the substance to be copied, or coated, must either be a conducting substance or be artificially rendered such. Thus, if I desire to coat a wax model or a glass model, it will not be sufficient to suspend it by a copper wire from the negative pole, for the wax or glass being a non-conducting substance will break the electric circuit, and no force will be available for coating it. It is necessary to enclose the model in some conducting envelope, which shall take the shape of the model in all its nicety. This can be done by coating it with some finely powdered conductor (plumbago is generally used), so that every point is covered.

This coating becomes itself coated by being the terminal plate of the negative pole. The model itself serves to give this coating the required shape, but is not otherwise of any value in the operation. Care must be taken to continue the plumbago coating to the wire of the battery, so as to form a continuous conducting line.

SUMMARY.

Sound, heat, light, &c., are the *accompaniments* of force, not the *terminations* of it. Page 357.

We can neither create nor destroy force, the origin of which is unknown to us. Page 357.

We can apply force only by means of media. Page 358.

The steam-engine is an example of the use of media to apply force. Page 358.

Combustion is an example of force acting in a manner not yet accounted for. Page 359.

Coal is the most convenient fuel. Page 359.

Water is the most convenient medium of force. Page 359.

Electro-plating is also an example of the utilisation of force. Page 360.

CHEMISTRY

IN ITS RELATION TO PHYSICS.

(1.) **Introduction.**—In speaking of the causes, effects, and nature of the phases of energy called Heat, Light, Electricity, &c., we have had frequently to talk of chemical composition and decomposition. Probably most of my readers are already more or less familiar with Chemistry, but some few may not be. For these I have written a few pages, which I trust will be excused by those who do not need them.

(2.) **Composition of Water.**—Take a saucer nearly full of water, and throw on it, lightly, a small piece of pure potassium. Immediately it will burst into flame, burn with a violet-coloured light, and be consumed. Contact with the water is the cause of its being set alight, and in burning it is absorbed by the water, which afterwards tastes differently from pure water, having somewhat the flavour of soda. But it is not that the water has had any effect on the potassium, but the reverse. The potassium has really affected the water, and broken some of it up into its constituent elements. **Water is made up of Oxygen and Hydrogen**, and **Potassium** has so much attraction for **Oxygen** that it will draw it out of the water, and leave only **Hydrogen.** That is, each drop of water, as it touches the **Potassium,** ceases to be water, and is broken up into **Oxygen** and **Hydrogen.** The **Oxygen** unites with the **Potassium,** while the **Hydrogen** passes away as gas into the air. The potassium having taken the oxygen into union with itself is no longer pure potassium, but potassic oxide, and this being dissolved in the water gives it the flavour spoken of. Pure **Sodium** will also, in a similar manner, separate, by mere contact, **Water** into its constituents, **Oxygen** and **Hydrogen.** The sodium will become sodic oxide by union with the oxygen obtained from the water, while, as before, the hydrogen will pass away as gas, but the water must

cease to be water before the sodium can be combined with the oxygen obtained by its decomposition.

We prove the presence of hydrogen in water in this way, by means of potassium or sodium, since we can easily collect the gas given off while the oxygen of the water is uniting with the potassium or sodium, and it proves to be pure hydrogen, which cannot have any source but the water. In the same way, by uniting water and pure chlorine at a high temperature, we enable the chlorine to combine with the hydrogen of the water, and the oxygen is set free, and can be collected as gas. Thus we can get from water both pure hydrogen and pure oxygen.

We know, therefore, that water contains both hydrogen and oxygen, and we can also prove that it contains no other element. For we can convert any given quantity of water into these two gases, and find nothing remaining. If we use potassium, we only get the hydrogen free, the oxygen being combined with the metal; if we use chlorine, we get only oxygen free, the hydrogen being combined. But if we subject water to the action of a galvanic current, we get it entirely converted into gases, each of which is quite free and pure.

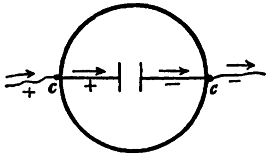


Fig. 207.

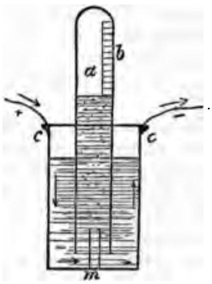


Fig. 208.

The means by which this is effected are described on page 200; it will suffice to say here that the two wires *c c* conduct a galvanic current through the water at *m*, and the result is its decomposition and the rise of the gases oxygen and hydrogen in the tube *a*.

Fig. 207 is the apparatus seen from above; fig. 208 the same seen sideways. The arrows show the direction of the current, and *b* is a scale to show the quantity of gas evolved.

That water is composed of hydrogen and oxygen, and only of these, may be still further proved by combining them again, and reconverting them into water, which may be done by passing through the mixed gases a galvanic current. So that water can be separated into its elements, and these may be reconverted into water by the same means —*i.e.*, electricity.

But we cannot take either hydrogen or oxygen from water

without taking both. We must consider water as made up in exceedingly small pieces, much smaller than the smallest drop we could take up on the point of a needle. Each of these minute drops is made of hydrogen and oxygen, and when we get either gas it is by breaking up some of these drops into their elements. If we take a lump of ice and pound it into the finest powder possible, each of these grains can be melted into water, from which hydrogen and oxygen can be obtained.

Fig. 209 shows, on a greatly magnified scale, the oxygen and hydrogen constituents of water, the two uniting to make the apparently single substance, water.

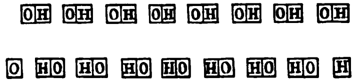


Fig. 209.

The two gases are also always united together in exactly the same proportion. If we decompose any given quantity of water into its elements, we may measure these elements either by weight or by volume. If by weight, we shall find the oxygen eight times as heavy as the hydrogen. If by volume, we shall find the hydrogen twice as much as the oxygen. Thus the oxygen is much heavier than the hydrogen: in fact, any volume of oxygen weighs sixteen times as much as the same volume of hydrogen. If, now, we put in the same vessel one ounce of oxygen and one-eighth of an ounce of hydrogen, we should find the hydrogen (though so much the lighter) occupied twice the room that the oxygen required. So, also, if we put the gases together so that the hydrogen occupies twice the room of the oxygen, the oxygen would be found to weigh eight times as much as the hydrogen. In either case the two gases could be converted into pure water, which would weigh exactly as much as the two gases together, but would occupy very much less room.

If an ounce of hydrogen and an ounce of oxygen be put together, the result will not be two ounces of water. The ounce of oxygen would unite with one-eighth of the hydrogen to make water weighing one ounce and one-eighth, while the remaining seven-eighths of an ounce of hydrogen would be left free and unaffected. So if we put together equal volumes of the two, the hydrogen will unite with half the oxygen, leaving the other half free.

The hydrogen and oxygen of which water is made, differ very much in their natures from water. Hydrogen will burn, and oxygen enables combustibles to burn more vividly than they can in ordinary air. Water neither burns nor assists combustion; on the contrary, it is usually looked on as the natural enemy to fire. Oxygen and hydrogen are both gases, and therefore both invisible; water is a visible fluid. Water is heavy and falls to the ground; its constituent gases are light, and rise in the air.

(3.) **Chemical Elements.—Oxygen** and **Hydrogen** are very important in a chemical view. They enter into combination with very many other elements, forming compounds of great chemical importance. Thus oxygen combines with very many of the other elements, just as we see it does with potassium and sodium. These combinations are called oxides, as—

Oxide of Potassium or **Potassic Oxide.**
Oxide of Sodium or **Sodic Oxide.**
Oxide of Iron or **Ferric Oxide.**
Oxide of Zinc or **Zincic Oxide.**
Oxide of Lead or **Plumbic Oxide.**

Hydrogen also combines with many of the other elements, thus—

Hydrogen and **Nitrogen**	unite to make	**Ammonia.**
Hydrogen and **Chlorine**	,,	**Hydrochloric Acid.**
Hydrogen and **Carbon**	,,	**Marsh Gas.**
Hydrogen and **Oxygen**	,,	**Water.**

These gases, **oxygen, hydrogen, chlorine, nitrogen,** and the solid, **carbon,** differ from water or any other *compound* substance, in that they are entirely *simple.* Out of water we can get oxygen and hydrogen ; out of ammonia we can get hydrogen and nitrogen. But from pure carbon we can get nothing but carbon, out of hydrogen nothing but hydrogen, and so on of the other elements. Each is homogeneous, and incapable of further analysis by any power at present in our hands.

Fig. 210 shows the simplest method of decomposing chemical compounds. The method is described at page 185.

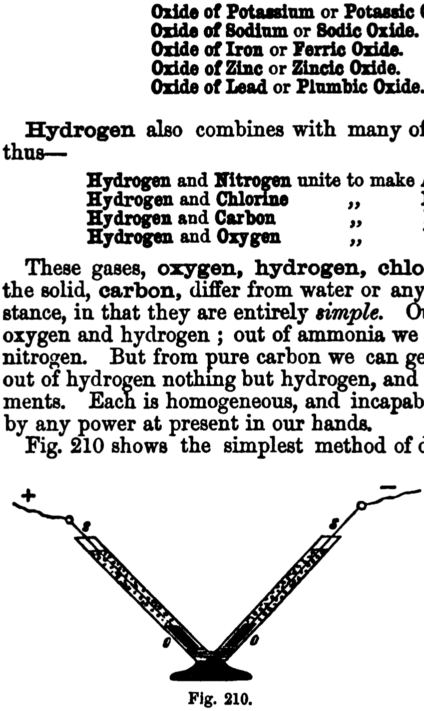


Fig. 210.

The number of these ultimate constituents (of various combinations, of which the whole world is made up) is not large. Some sixty simple substances comprise the elementary materials of the universe. Of these, one-third may be considered of primary importance, being very widely spread, and necessary for the continuance of the earth, water, and air, and for the preservation of life. Another third may be classed as of secondary value, being of much less extent, but of great economic value, such as **zinc, tin, gold, silver,** &c. The remaining third are of but little general importance. The following table gives the names of the elements of first and second rate importance, the more important being printed in larger type than the other :—

Gases.

Chlorine. **Fluorine.** **Hydrogen.** **Nitrogen.** **Oxygen.**

Liquids.

Mercury. Bromine (?)

Solids.

Aluminium.	Barium.	**Bromine.**	Chromium.
Antimony.	Bismuth.	Calcium.	Cobalt.
Arsenic.	Boron.	Carbon.	Copper.
Gold.	**Magnesium.**	Platinum.	**Sodium.**
Iodine.	**Manganese.**	**Potassium.**	Strontium.
Iridium.	Nickel.	Rhodium.	**Sulphur.**
Iron.	Palladium.	**Silicon.**	Tin.
Lead.	**Phosphorus.**	Silver.	Zinc.

From what we have already learned respecting water we infer—

(1.) **That water always consists of the same elements.**

(2.) **That these elements always combine in water in the same ratio.**

(3.) **That these elements in that ratio can always be combined to form water.**

From similar experiments with other compounds and elements —*i.e.*, by analysing other compounds, and recombining their elements—we might extend our inferences to saying—

(1.) **That the same compound substance always contains the same elements.**

(2.) **That these elements are (in any given compound) always united in the same ratio.**

(3.) **That the same elements, in that ratio, if capable of being united, will always produce the same compound.**

This reservation is necessary, because in many cases we can analyse a complex substance, and ascertain the number and quantity of its elements, without being able to reconstitute it from those elements.

We shall find that these three principles do underlie all chemical combination ; and this fact enables us to write chemical facts in a kind of shorthand—equally easy to write and to read—which tells us the composition of each substance both as to its elements and the ratio in which they are present. Thus *Water is composed of hydrogen and oxygen in the ratio of two volumes of hydrogen to one of oxygen.* If we express hydrogen by H, and oxygen by O, then HO will express hydrogen and oxygen, and H_2O will express that the hydrogen is present in twice the volume of the oxygen ; and thus H_2O will express water in the simplest and most complete chemical manner possible. In **hydrochloric acid** we have **hydrogen** and **chlorine** in equal volumes. If we represent hydrogen by H, and chlorine by Cl (C being used for car-

bon), we have HCl representing the elements of hydrochloric acid, and also the fact of their union in equal volumes. In ammonia we have three volumes of hydrogen to one of nitrogen, and (nitrogen being written N) we have, as the expression of ammonia, H_3N.

The following table gives some of the more important combinations of two elements :—

	Symbol.	Cl Chlorine.	F Fluorine.	I Iodine.	N Nitrogen.	O Oxygen.
Carbon, .	C					CO_2 Carbonic gas (carbonic acid).
Calcium, .	Ca	$CaCl_2$ Chloride of lime.				CaO Oxide of calcium (lime).
Iron, . .	Fe					Fe_2O_3 Oxide of iron (iron rust).
Hydrogen,	H	HCl Hydrochloric acid.	HF Hydrofluoric acid.	HI Hydriodic acid.	H_3N Ammonia.	H_2O Oxide of hydrogen (water).
Mercury, .	Hg	$HgCl_2$ Chloride of mercury (corrosive sublimate).				HgO Oxide of mercury.
Magnesium,	Mg					MgO Oxide of magnesium (magnesia).
Sodium, .	Na				NaCl Chloride of sodium (salt).	
Phosphorus,	P					P_2O_5 Phosphoric anhydride (phosphoric acid).

In the table there are some small numerals, 2 and 3. Thus $CaCl_2$ means that if any quantity of the compound be converted in a *gas*, there will be twice as much chlorine *by volume* as calci-

um. So H_2O (water) means that in any quantity of steam there is twice as much hydrogen as oxygen by volume. Where there are no numerals, such as CaO, HgO, or HCl, the volumes of the two constituents are equal, *when in the gaseous form.*

Notice how readily hydrogen and oxygen enter into combination with other elements. Also hydrogen seems, although a gas, to resemble the metals in combining character.

CONCLUSION.

I have now exhausted, not my subject, but my space. I have tried in this book to do little more than to excite my reader's attention to the phenomena of the outer world, and to put before him in general language some of the laws governing these phenomena. I hope soon to offer him a second book, in which I will try to answer, in detail and accurately, some of the many questions which I hope this book will induce him to ask, and which it does not pretend to answer.

TABLES.

THESE tables are mostly abridged from the Reports to the British Association. They are frequently somewhat discordant, but I have preferred to leave them so, as showing the difficulties of scientific research, and the variety of the results obtained.

LIGHT.

TABLE I.—THE RAYS OF THE SUN.

(1.) The sun's rays have three kinds of effect:—
1. Luminous or light-giving.
2. Calorific or heat-giving.
3. Actinic or chemical.

(2.) In spring the actinic rays, and in autumn the heat rays, are far in excess of the others.

(3.) The most luminous rays show least chemical action on *inorganic* matter.

(4.) The most luminous rays influence all *organic* matter.

(5.) ,, ,, protect bodies from the chemical action of the other rays.

(6.) Luminosity and actinism appear to be antagonistic.

TABLE II.—VELOCITY OF LIGHT.

(1.) Estimated by Fizeau at 167,528 geographical miles per second.
(2.) ,, Delambre at 167,976 ,, ,,
(3.) ,, Struve at 166,096 ,, ,,
(4.) ,, Foucault at 160,920 ,, ,,

The estimation of Foucault is lower than the other, and agrees with the decreased estimate of the distance of the sun from the earth.

TABLE III.—INFLUENCE OF LIGHT ON VEGETATION.

(1.) Light prevents the germination of seeds.
(2.) Actinism assists this germination.
(3.) Light helps the plant to decompose CO_2.

(4.) Light and actinism without heat prevent the development of reproductive organs.

(5.) Heat facilitates flowering and reproductive development.

(6.) Light and heat are essential to formation of colouring material.

(7.) The amount of growth and wood in a plant varies with the light rays falling on it, as may be shown by covering plants with different-coloured glasses.

	Colour of glass cover.				
	White.	Red.	Yellow.	Blue.	
1st plant,	8.2	8	8.1	7.2	Percentage of woody fibre; showing that white light was the best, and blue the worst, for growth.
2d plant,	22.7	21.5	22.5	20.5	
3d plant,	12.5	11.8	12	10.7	

(8.) Different-coloured glass affects the passage of light rays differently.

	Colour of glass.				
	White.	Red.	Yellow.	Blue.	
Luminous rays, .	97	56	90	51	Percentage of rays of each kind transmitted.
Heat rays, . . .	75	84	82	60	
Actinic rays, . .	93	29	20	94	

The small percentage of actinic rays transmitted by yellow glass enables photographers to light their laboratories by means of this glass, and so to work in the light. At one time they had to work in darkness, after taking the impression in the camera, because of the action of light. A piece of photographic paper submitted at the same time to action of two rays of light, one ordinary sunlight, the other transmitted through yellow glass, remained unaffected, the luminous rays being apparently antagonistic to actinic rays. See Table I. 6.

Table IV.—Substances chemically affected by the Sun's Rays.

Silver, gold, platinum, mercury, iron, copper, manganese, lead, nickel, tin, cobalt, antimony, bismuth, phosphorus, resins, &c.

Of silver, the most sensitive compounds are the nitrate, chloride, and bromide; of gold, the chloride and chromate; of platinum, the chloride, iodide, and bromide.

Table V.—Wave-Lengths of Light.

Colours of the spectrum.	Lines in the spectrum.	Wave-length in inches.	
Red . . .	A . . .	.0000299	The numbers give the decimals of an inch estimated as the extent of each wave or vibration at the parts of the spectrum where the dark lines occur. The numbers increase from the violet end towards the red end, showing that the size of the waves decreases steadily from the red to the orange, from the orange to the yellow, &c., to the violet.
Orange .	B . . .	.0000268	
	C . . .	.0000256	
Yellow . .	D . . .	.0000230	
Green. . .	E . . .	.0000205	
Blue . . .	F . . .	.0000189	
Indigo . .	G . . .	.0000168	

TABLE VI.—REFRACTION.

(1.)	Refractive indices.
Solids.	
Diamond,	2.55
Phosphorus,	2.22
Sulphur,	2.12
Ruby,	1.78
Iceland-spar(a),	1.65
„ (b),	1.50
Glass (flint),	1.57
„ (crown),	1.51
Ice,	1.31
Liquids.	
Bisulphide of carbon,	1.64
Alcohol,	1.36
Ether,	1.35
Water,	1.33
Gases.	
Chlorine,	1.0008
Carbonic gas,	1.0005
Ammonia,	1.0004
Nitrogen,	1.0003
Air,	1.0003
Oxygen,	1.0003
Hydrogen,	1.0001
No refraction,	1.0000

(2.) Effects of temperature on refraction.

Temp. C.	A.	D.	H.	Length.	Dispersion.
(A.) *Bisulphide of Carbon.*					
0°	1.621	1.644	1.717	0.095	.148
10°	1.614	1.634	1.708	0.093	.147
20°	1.607	1.626	1.699	0.091	.146
30°	1.599	1.618	1.689	0.090	.145
40°	1.591	1.610	1.681	0.089	.145
(B.) *Distilled Water.*					
0°	1.329	1.333	1.343	0.0147	.0429
10°	1.328	1.332	1.343	0.0146	.0439
20°	1.327	1.332	1.342	0.0148	.0445
30°	1.327	1.330	1.341	0.0145	.0438
40°	1.325	1.329	1.340	0.0148	.0449

A. D. and H. are the spectrum lines so named.

Notice the greater differences in the bisulphide than in water, and also the greater regularity of decrease.

(3.) In every substance the refractive index diminishes as the temperature increases.

(4.) In every substance the length of the spectrum diminishes as the temperature increases.

(5.) The dispersion sometimes increases and sometimes decreases as the temperature increases.

(6.) The solid and liquid conditions have different indices. For example:—

	Temp.	A.	D.	H.
Solid phosphorus,	25° C.	2.105	2.144	2.309
Liquid phosphorus,	35°	2.308	2.074	2.226

TABLE VII.—POLARISATION.

(1.) The metals have no angle of complete polarisation by reflection for ordinary light.

(2.) The metals and some other bodies (indigo, diamond, sulphur, &c.) confer elliptic polarisation by reflection on plane polarised light.

(3.) The water of Lake Geneva, remarkable for blueness, was found to reflect polarised light, the line of complete polarisation being at right angles to the line joining the water and the sun.

TABLE VIII.—STANDARD OF LIGHT.

The want of some definite unit of light has led Mr Crookes to suggest the following :—A glass lamp having a neck aperture of $\frac{1}{4}$ inch, burning a liquid fuel composed of alcohol and benzol, in the proportion of 5 volumes of alcohol to 1 volume of benzol. The alcohol to be of 0.805 specific gravity, and the benzol to boil at 81° C. The wick-holder to be a platinum tube, and the wick 52 pieces of platinum wire, each $\frac{1}{100}$ inch in diameter. The consumption of fuel would be 136 grains per hour, giving a uniform luminosity.

TABLE IX.—AURORA, *October* 25, 1870, *London.*

The spectrum of this magnificent phenomenon gave a red line near C, a yellow line near D, a pale line near F, and one still paler beyond F.

HEAT.

TABLE I.—KINDS OF HEAT.

(1.) Heat is sometimes divided into dark and light heat.
(2.) Dark heat emanates from all terrestrial bodies.
,, ,, is absorbed by all bodies in proportion to their *texture*.
,, ,, is unable to pass through glass.
(3.) Light heat is given off at a higher stage of incandescence.
,, ,, is absorbed by all bodies in proportion to *colour*.
,, ,, is transmitted by all transparent substances.
,, ,, has the power of exciting vision.

TABLE II.—SOURCE OF HEAT IN THE SUN.

(1.) The sun may be an intensely-heated body, gradually cooling by radiation.

(2.) It may give out heat by means of combustion.

(3.) In either case its existence seems terminable: in the first case by cooling; in the second by exhaustion. If fuel were supplied from without, the force required to supply it would be probably greater than that reproduced by the combustion.

TABLE III.—RADIATION AND ABSORPTION OF HEAT.

(1.) Different bodies, when heated, emit different kinds of heat.

(2.) Some bodies emit only one kind, some several kinds.

(3.) The amount of absorption increases with the thickness.

(4.) Rock-salt is diathermic, because it radiates and absorbs only one and the same kind of heat.

(5.) Heat from rock-salt is almost entirely absorbed by fluor-spar.

(6.) Heat from fluor-spar is only $\frac{1}{3}$ absorbed by rock-salt.

(7.) If a spectrum of heat from rock-salt could be visible, it would be seen to contain one band only, resembling that of sodium, which is one of its constituents.

(8.) The effect of a heated body on a thermometer is proportional to the angle it subtends upon it.

(9.) Different temperatures mean different wave-lengths.

TABLE IV.—RADIATION AND ABSORPTION.

(1.)	Radiation.	Absorption.
Rock-salt, . .	51	25
Fluor-spar, . .	95	49
Red-lead, ...	118	57
Oxide of cobalt,	121	62
Sulphide of iron,	131	66
Lampblack, . .	163	100

(2.)	Radiation.	Absorption by rock salt.
Rock-salt, . . .	24	38
Iodide of lead, .	36	26
Sulphate of zinc,	36	26
Chloride of lead,	39	?
Sugar, ...	52	25
Oxide of lead, .	56	?
Sulphate of lime,	59	26
Carbonate of zinc,	62	26
Iodide of copper,	63	24
Red oxide of iron,	63	24
Black oxide of iron,	65	21

The first column is the proportion of heat radiated from the surface of a Leslie's cube covered with the substance named in a finely-powdered state. The second column shows the proportion of this heat absorbed by a rock-salt lens on which it falls.

TABLE V.—TRANSMISSION.

(1.) The quantity of heat that traverses a body is proportional to the temperature of the source.

(2.) This quantity is also proportional to the thickness of the traversed body.

(3.) Rock-salt is equally diathermic to all kinds of heat.

(4.) Diathermacy is not proportional to transparency.

(5.) Thermometer cooled from 100° to 0° C. *in vacuo*, $10^{m.}$ $5^{s.}$; in air, $7^{m.}$ $3^{s.}$; in water, $1^{m.}$ $5^{s.}$; in mercury, $0^{m.}$ $36^{s.}$

TABLE VI.—EXPANSION.

Expansion for 1° F.		From 0° to 100° C.		
Zinc, cast,	.0000213	Mercury, ...	.015	For all gases the expansion is about .00366, or $\frac{1}{273}$ (which may be also written $\frac{3}{820}$). This means that a column of gas will expand $\frac{1}{273}$ of its length for every 1° C.
,, tube,	.0000177	Water, ...	.05	
Tin, cast,	.0000162	Turpentine, . . .	.07	
,, tube,	.0000193	Ether, ...	.08	
Brass, .	.0000130	Alcohol, ...	.11	
Copper, .	.0000121			
Glass, .	.0000052	This is the total expansion for 100°; for 1° it would be less than $\frac{1}{100}$ of this if near 0°, and more than $\frac{1}{100}$ if near 100°, the coefficient increasing gradually from 0° to 100°.		

TABLE VII.—SPECIFIC CAPACITY FOR HEAT.

(1.)

Between 0° and 100° C.	Solid.	Liquid.
Water, . .		1.000
Turpentine,		.425
Sulphur,	.202	
Graphite, .	.201	
Phosphorus,	.189	
Glass, . .	.177	
Diamond, .	.146	
Iron, . .	.109	
Copper, .	.094	
Brass, . .	.093	
Zinc, . .	.092	
Tin, . . .	.056	
Silver, . .	.055	
Mercury, .		.033
Antimony,	.050	
Platinum, .	.035	
Gold, . .	.032	
Bismuth, .	.030	

(2.)

Gases.	Specific gravity.	Specific heat for equal vols.	Specific heat for equal weights.
Air, ...	1.000	1.000	1.000
Nitrogen, . .	.972	.961	.988
Hydrogen, .	.069	.131	1.894
Carbonic oxide,	.972	1.050	1.080
Carbonic gas,	1.527	1.667	1.091
Nitrous oxide,	1.527	1.780	1.165

Table VIII.—Conduction of Heat.

(1.) Pure Metals.		(2.) Alloys.		(3.) Various estimates by different observers; the variations probably due to impurities.	
Silver	1000	Pure silver	1000	Silver being 1000, copper is estimated by	
Gold	981	Tin and Lead.		Bequerel	953
,, (1 per cent of silver)	840	1 Sn + 5 Pb	301	Reiss,	672
Copper, rolled	845	5 Sn + 1 Pb	386	Lenz	734
,, cast	811	Tin and Zinc.		Davy	912
Aluminium	665	5 Sn + 1 Zn	442	Christie	660
Zinc, rolled	641	1 Sn + 5 Zn	572	Buff	950
,, cast vertically	628	Lead and Antimony		Harris	1000
,, ,, horizontally	608	1 Pb + 5 Sb	215	Pouillet	730
Cadmium	577	1 Pb + 1 Sb	276	Arndtsen	987
Iron, malleable	436	Antimony and Bismuth.			
Tin	422	1 Sb + 5 Bi	75		
Steel	397	5 Sb + 1 Bi	159		
Platinum	380	Copper and Tin.			
Sodium	365	1 Cu + 5 Sn	459		
Cast iron	359	5 Cu + 1 Sn	705		
Lead	287	Copper and Zinc.			
Antimony	215	1 Cu + 5 Zn	657		
Bismuth	61	5 Cu + 1 Zn	780		
Mercury	54				
		Pure copper	778		
		100 Cu + 2.5 P	7.2		
		,, + .95 P	23.2		
		,, + .13 P	67.6		
		,, + .18 S	88.5		
		,, + 3.2 Zn	56.9		
		,, + 1.06 Fe	26.9		
		,, + 4.9 Sn	19.5		
		,, + 2.5 Arg	79.3		
		,, + 3.5 Au	65.3		

ELECTRICITY.

Table I.—Conduction of Electricity.

(1.)

Conductors.	At 0° C.	At 100° C.
Silver	1000	715
Copper No. 3	774	543
" No. 2	720	505
Gold	551	392
Sodium	374	
Aluminium	337	
Copper No. 1	306	
Zinc	273	200
Magnesium	254	
Cadmium	221	147
Calcium	221	
Potassium	208	
Lithium	190	
Iron	144	
Palladium	126	
Tin	114	81
Platinum	105	
Lead	77	50
Argentine	76	
Strontium	67	
Antimony	42	32
Mercury	16	
Bismuth	11	8
Graphite	0.6	
Gas-coke	0.3	
Tellurium	0.007	
Red phosphorus	0.00001	

(2.)

Various estimates of Conductibility. The variations due to impurity, molecular condition, annealing, and temperature.

	Lenz.	Bequerel.	Matthiessen.
Silver	1000	1000	1000
Copper	734	953	999
Gold	585	669	780
Cadmium	...	263	237
Zinc	...	257	290
Tin	226	150	123
Iron	130	131	144
Lead	107	88	83
Platinum	104	86	105
Mercury	34	18	16

(3.)

Conductibility of Alloys.*

	At 0°.	Decrease per cent to 100°.
Pure metals generally		29.3
Gold 78.3, Silver 14.3, Copper 7.4 = 100	444	15.5
Silver 95.0, Platinum 5.0 = 100	316	11.3
Gold 85.0, Iron 15.0 = 100	27	27.9
Gold 95.3, Iron 4.7 = 100	23	3.8
Gold 90.0, Iron 10.0 = 100	21	17.5
Silver 75.0, Palladium 25.0 = 100	85	3.4
Silver 66.6, Palladium 33.4 = 100	67	3.1

(4.)

Gold 95, Iron 5 = 100, at 15°, 235; at 56°, 231; at 100°, 227; conductivity.

If λ = conductivity and t the temperature; then at all temperatures we have, $\lambda = 20.967 + .010057t + .00001052t^2$ for this alloy.

* This table was the result of an inquiry for a conductor having a maximum conductivity with a minimum variation with temperature.

TABLE II.—ELECTRICAL RESISTANCE.

(1.) STANDARDS.

PURE METALS.—*Advantage.* Electrotype copper has always the same conductivity.

,, *Disadvantages.* Influences of annealing and of temperature.

MERCURY.—*Advantage.* Mercury has no change of molecular condition.

,, *Disadvantages.* Impurity and amalgamation affect conductivity. It must be in a tube, which may be broken, and may alter in volume.

ALLOYS.—*Advantages.* Small variation in different specimens; molecular condition alike in all; annealing and temperature have but small effects.

,, *Disadvantage.* Alloys alter with time more than pure metals.

(2.) EQUATIONS FOR STATICAL OR FRICTIONAL ELECTRICITY.

(α) $C = \frac{E}{R}$. The *current* equals the *force* divided by the *resistance.*

(β) $Q = Ct$. The *quantity* equals the *current* multiplied by the *time.*

(γ) $W = C^2Rt$. The *work* equals the square of the *current* multiplied by the *resistance* and by the *time.*

(δ) $F = \frac{Q}{d^2}$. Mutual *repulsion* (F) equals *quantity* divided by the square of the *distance.*

(3.) EQUATIONS FOR DYNAMICAL OR GALVANIC ELECTRICITY.

(α) (β) (γ) exactly as above.

(δ) $F = \frac{C\,L^m}{k^2}$

(η) $C = \frac{H\,k^2}{L}$ tan. d.

(κ) $F = S\,L\,C.$

(λ) $W = V\,S\,L\,C.$

(μ) $E = V\,S\,L.$

(ν) $R = \frac{L^2\,V}{4\,k^2 \text{ tan. d.}}$

The object of this series of equations is to find the last one, $R = \frac{L^2\,V}{4\,k^2 \text{ tan. d.}}$ of which the right hand member contains only known quantities, and therefore gives the value of R. The symbols have the following meanings: m = the strength of a magnet. L = the length of a wire bent in a circle round it having a radius = k. The angle through which the magnet moves by the force of the current through the wire = d. The force which causes this movement = f. H = the earth's magnetic force. V is the velocity of a straight conductor crossing the lines of magnetic force having an intensity of S. By giving the right values to L, V, k, and d, we can find a material representative of any given resistance R.

TABLE III.—UNITS OF ELECTRICAL RESISTANCE.

Siemen's mercury unit, ...	.9564
Matthiessen's ,, ...	.9646
Weber's absolute measure, $\frac{10{,}000{,}000 \text{ metres}}{\text{second.}}$ . . .	.9191
British Association unit, ...	1.0000
All the above are nearly the same.	
Matthiessen's one mile of copper wire $\frac{1}{16}$ inch diameter,	13.59

Table IV.—Great Induction-Coil of the Polytechnic Institution.

Length, 9 ft. 10 in.; *diameter*, 2 ft.; *weight*, 15 cwt.

Primary wire.—3770 yards of copper wire .0925 in. diameter, weight 145 lb., arranged in 6000 coils round a core of soft iron; resistance, 2.2 B. A. units.

Secondary wire.—150 miles of .015 in. diameter, covered throughout with silk; weight, 606 lb.; resistance, 33.560 B. A. units.

Soft iron core.—A bundle of very soft iron wires, each .0625 in. diameter; total diameter, 4 inches; weight, 123 lb.

The primary and secondary coils are separated by an ebonite tube 8 ft. long and ½ in. thick. A *Bunsen's battery* of from 5 to 50 cells is used to excite the coil.

Number of cells used, 5, 10, 15, 20, 25, 30, 35, 40, 50.
Length of spark in inches, 12, 14, 17.5, 21.25, 23, 23.5, 26, 27.5, 29.

Table V.—Thermo-electricity.

	Iron.	Silver.	Platinum.	Gold.	Copper.
Iron.	A 10 → B 2 → C 0	A 12 → B 1 → C 2 ← D 5 →	A 10 → B 10 ← C 10 ←	A 15 → B 2 → C 4 ← D 4 →	A 100 ← B weak → C 3 ← D 3 →
Silver.	A 8 → B weak → C 2 → D 5 ←	A weak → B weak → C 0	A 100 ← B 10 ← C 12 ←	A 10 ← B weak ← C 1 ←	A 190 ← B 2 ← C 2 ←
Platinum.	A 12 → B 10 → C 10 →	A 15 → B 15 → C 12 →	A 5 ← B 0 C 0	A 10 → B 10 → C 10 →	A 80 ← B 10 → C 15 →
Gold.	A 15 → B weak → C 3 → D 4 ←	A 10 → B weak → C 2 →	A 5 ← B 10 ← C 10 ←	A weak ← B weak → C 0	A 170 ← B weak ← C weak →
Copper.	A 90 ← B weak → C 3 → D 3 ←	A 210 ← B weak → C 2 →	A 250 ← B uncertain ← C 15 ←	A 300 ← B weak ← C weak ←	A 220 ← B weak ← C 0

The metal named above is always to the right hand; that named at the side, to the left hand. The two metal wires were each looped at the end, and joined as two links of a chain. The numbers show the force of the current, and the arrows its direction.

A. The contact was loose, and the heat applied to the right-hand loop.
B. The contact was tight, and the heat applied to the right-hand loop.
C. The contact was tight, and the heat applied to the middle of the two loops.
D. The same as C, but to a higher temperature.

(1.) TABLE VI.—THERMO-ELECTRIC INVERSIONS.

C. —14°	—1.5°	8.2°	36°	38°	44°	44°	64°	99°	121°	130°	162.5°	237°	280°
Platinum. Brass.	Platinum. Silver.	Platinum. Zinc.	Platinum. Lead.	Platinum. Brass.	Platinum. Tin.	Lead. Brass.	Platinum. Copper.	Platinum. Brass.	Platinum. Lead.	Platinum. Tin.	Iron. Cadmium.	Iron. Silver.	Iron. Copper.

(2.) At the temperature marked above any pair of metals there is *no* electric current for that pair.

(3.) The direction of the current changes as the temperature passes through this, being the reverse above to what it is below.

(4.) Some pairs have more than one zero-point—notice platinum and brass, platinum and tin, &c.

TABLE VII.—ELECTROLYSIS.

A No. of Cells in series.	B No. of Cells in quantity.	C Surface of each Battery Plate in sq. in.	D Surface of Electrodes in sq. in.	E Liquid in Battery.	F No. of cubic inches of Gas produced per minute.
1	1	8	8	1 volume of sulphuric acid + 4 volumes of water. Nitric acid, specific gravity 1.39.	a trace only
,,	,,	,,	72		,,
2	1	,,	72		6.7
,,	,,	,,	32		6
,,	,,	,,	8		5.2
,,	,,	,,	1		2.8
,,	,,	,,	wire		0.9
2	4	32	72		20.5
,,	,,	,,	64		20.5
,,	,,	,,	56		20.3
,,	,,	,,	48		20
,,	,,	,,	40		20
,,	,,	,,	32		19.4
,,	,,	,,	24		18.8
,,	,,	,,	16		16
,,	,,	,,	8		12
,,	,,	,,	1		3.5
,,	,,	,,	wire		1

(1.) A gives the number of cells or groups of cells arranged for intensity —*i.e.*, the positive pole of one cell connected with the negative pole of the next.

(2.) B gives the number of cells arranged for quantity—*i.e.*, all the positive poles connected, and all the negative poles also.
(3.) C shows the number of plates in each quantity arrangement—1 cell = 8 in.; 4 cells = 32 in.
(4.) D gives the surface of the electrodes—*i.e.*, the surface in contact with the water to be decomposed. This was alterable at pleasure.
E and F explain themselves.

MAGNETISM.

TABLE I.—VARIATIONS.

(1.) DIP greatest when sun and moon are in conjunction; least when sun and moon are in opposition.
(2.) FORCE least when the sun and moon are in either conjunction or opposition; greatest when the sun and moon are in quadrature.

TABLE II.—DIP, DECLINATION, AND INTENSITY.

(1.) Station.	Date.	Amount.	(2.) Station.	Dip.	Declination.	Intensity.
Kew	Aug. 1868	68° 3′	Brest	66.4°	21°	4°
Greenwich	,,	67° 58′	Vannes	66.5°	20.2°	4.1°
Norwich	,,	68° 17′	Laval	65.8°	19°	4.1°
Brussels	Sept. ,,	67° 6′	Angers	65.1°	19°	4.2°
Utrecht	,,	67° 43′	Bayonne	62.5°	18.3°	4.5°
Vienna	,,	63° 38′	Amiens	66.6°	18.3°	4.0°
Munich	,,	64° 7′	Poitiers	64.4°	18.3°	4.2°
Paris	Oct. ,,	65° 49′	Bordeaux	63.3°	18.2°	4.4°
Greenwich	Dec. ,,	67° 58′	Paris	65.8°	17.8°	4.1°
These results were all observed by the same person.			Toulouse	62.0°	17.1°	4.5°

TABLE III.—STRENGTH OF MAGNETS.

(1.) The usual equation is $P = 10.33 \sqrt[3]{W^2}$, meaning that the power P is equal to $10\frac{1}{3}$ times the cube root of the square of the magnet's weight.
(2.) Herr Logeman, in 1850, produced magnets of greater power, by passing horse-shoe-shaped pieces of steel several times through a helix of copper wire connected with one or two elements of a Grove's battery.

					$P = 10.33 \sqrt[3]{W^2}$, gives
Magnet	A,	weighing	1 lb.,	supported 28½ lb.	about 10 lb.
,,	B,	,,	12½ ,,	,, 150 ,,	,, 54 ,,
,,	C,	,,	52 ,,	,, 430 ,,	,, 140 ,,

Table IV.—Electro-Magnetism.

Given a battery, a helix of wire, and a bar of soft iron, then

(1.) The amount of magnetism varies with the strength of the current.

(2.) The amount of magnetism is independent of the thickness of the wire.

(3.) The amount of magnetism is *practically* independent of the diameter of the coil.

(4.) The amount of magnetism varies with the diameter of the soft-iron rod.

(5.) The attractive force of electro-magnets is proportional to the square of the force of the current by which they are magnetised.

Table V.—Attraction of Magnets.

(1.) A horse-shoe soft-iron bar, 13½ inches across the poles, diameter of pole 2½ inches, with 1690 feet of copper wire in ten equal helices, excited by a battery with one vol. of SO_3 in 50 of water.

(2.) No. of coils used.	Weight supported.	(3.) No. of coils.	Weight attracted at a distance of—					
			Contact.	$\frac{1}{16}$ in.	$\frac{1}{8}$ in.	$\frac{1}{4}$ in.	$\frac{3}{8}$ in.	$\frac{1}{2}$ in.
1	2¼	1	12¼lb.					
2	3¼	2		5¾				
3	7¼	3		9¼	4½	3¼	2¼	
4	11¼	4		12¼	3¾	3¼	2½	
5	13½	5		12¼	4½	2¼	3¼	
6	18¾	6		18¼	7¼	3	3	3¾
7	22¾	7		19¼	5¾	2¼		
8	26¾	8		30¼	8¾	4¼	9¾	7¾
9	19¼	9		21¼	8¼	9½	6¼	5¼

Table VI.—Electro-Magnetic Force.

In 1838, a boat 28 feet long, 7½ feet wide, drawing 2¾ feet of water, and carrying 14 persons, was propelled at 1½ mile per hour by an electro-magnetic machine, excited by 320 pairs of plates, each of 36 square inches, excited by sulphate of copper.

In 1839, the same boat was propelled at 3 miles per hour by an improved machine, excited by 64 plates, each 36 square inches, excited by sulphuric and nitric acids.

THE METRIC SYSTEM OF MEASUREMENT.

TABLE I.—COMPARISON.

	Names.	Length.	Surface.	Capacity.	Weight.
Multiples.	Myria ...	10,000 mètres			10,000 grammes
	Kilo	1000 mètres		1000 litres	1000 grammes
	Hecto ...	100 mètres	100 ares	100 litres	100 grammes
	Déka.....	10 mètres		10 litres	10 grammes
	UNIT....	1 mètre	1 are	1 litre	1 gramme
Divisions.	Deci	.1 mètre		.1 litre	.1 gramme
	Centi	.01 mètre	.01 are	.01 litre	.01 gramme
	Milli	.001 mètre			.001 gramme

TABLE II.—LENGTH.

Names.	English Equivalents.		
	Yards.	Feet.	Inches.
Myriamètre . .	10,936.33 (6.2137 miles)		
Kilomètre . . .	1093.633		
Hectomètre . .	109.363		
Dékamètre . .	10.936	32.809	
Mètre	1.094	3.264	39.371
Décimètre . . .			3.937
Centimètre . .			0.394
Millimètre . .			0.039

TABLE III.—CAPACITY.

	Gills.	Quarts.	Gallons.
Hectolitre .		88.04	22.010
Dékalitre .		8.804	2.201
Litre . .	7.04	0.880	
Décilitre .	0.704	0.088	
Centilitre .	0.070		

TABLE IV.—WEIGHT.

	Avoirdupois.					Troy.
	Drams.	Ounces.	Pounds.	Qrs.	Cwt.	Pounds
Tonne . .					19.684	2677.4
Quintal . .			220.46	7.873	1.968	
Myriagramme .			22.046	.787	.196	
Kilogramme .		35.270	2.204	.0787		
Hectogramme .	56.440	3.527	.220			Grains.
Dékagramme .	5.644	.352				—
Gramme . .	.564					15.432
Décigramme .						1.543

TABLE V.

Measures.	In terms of standard Yards.	In Inches.
The yard	1.0000	36.000
The metre	1.0936	39.370
The toise	2.1315	76.734
Royal Society's metre . . .	1.0936	39.369
Ordnance metre	1.0937	39.374
Ordnance toise	2.1316	76.739
Prussian toise	2.1315	76.734
Belgian toise	2.1315	76.734
Russian double toise . . .	4.2630	153.468
Indian ten-feet bar	3.3334	120.000
Australian standard . . .	3.3333	119.998

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